Strategic Planning for Ontario Fisheries

Policy Development

The Identification Of Overexploitation

Report of SPOF
Working Group Number Fifteen

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Ministry of Natural Resources

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THE IDENTIFICATION OF OVEREXPLOITATION

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EXECUTIVE SUMMARY

Instances of overexploitation have been ineffectively countered in Ontario because of delayed recognition and action. Convincing evidence of fishing excesses would surface only after the resilience of a stock was undermined and a downward trend established. Recovery under these circumstances would be slow and often dependent on some coincidence of favourable effects.

Despite a heightened awareness of the effects of exploitation on fish stocks and fish communities, the risk of doing too little too late remains. To lessen this, a set of parameters and procedures for quantifying fishing effects and some benchmarks by which results may be interpreted are proposed. As well, questions or issues that should be asked or taken into account in any analysis of fishing impact are raised.

In a conventional sense, overexploitation entails a loss in the ability of a fishery resource to sustain yields at some theoretical upper limit. This concept has lacked practical application because maxima are ill-defined and losses tend to reach significant proportions before being discernible against the background of natural variability in biological systems. A definition of overexploitation is adopted which incorporates the traditional view but also considers fishing to be excessive when the resource is placed at high risk of collapse or displacement. This could precede a loss in yield.

Changes which fish stocks undergo when exploited are reviewed and a selection is made of responses which have practical application as indicators of stress. These fall into three categories: effects relating to population size; those relating to population structure; and a final group relating to physiological processes. The last of these represent the major mechanisms for compensation. This report is based on the proposition

that stress from exploitation can be ascertained from the degree of change (all else being equal) and that tolerance to increased fishing will be a function of the scope for additional compensation.

No single indicator can be considered definitive. The various indicators (yield, abundance, age structure, total mortality, mean age of catch, variation in year class strength, growth and age at maturity) are intended to be used in some combination. They provide only circumstantial evidence of overexploitation and an accumulation of such evidence is required for a judgement decision.

The indicators are applied on a trial basis using data sets from two lakes judged to be borderline cases with respect to overexploitation. A consensus is reached concerning the status of these lakes, but it is also apparent that the indicators require refinement (a greater accounting of variability) and calibration.

Other stresses can impart changes similar to those associated with exploitation and use of the indicators must be tempered accordingly. In multiple stress situations, the indicators become indicators of combined stress and it remains for the manager to decide which one(s) is threatening a fishery. Clues will come from the indicators.

INTRODUCTION

Background

Overexploitation is prominent among reasons cited for the erosion of fishery resources and the loss of recreational and business opportunities in Ontario (Loftus 1976). Various explanations can be advanced (Anonymous 1978), but in retrospect one stands out. Too often, overexploitation was not recognized as a threat or a reality, certainly not in time to take preventative or remedial action while a stock still had the capacity to respond. Populations had to fail before it was generally accepted that overfishing had occurred. Then, recovery frequently depended on some coincidence of favourable effects (Larkin 1977).

It is unfortunate, but true, that the risk of doing too little too late remains. Managers are now quite conscious of the threat of overfishing and they have a much better awareness of the effects of fishing on stocks. Nevertheless, they continue to have difficulty discerning when to halt the development of a fishery or, in some cases, deciding whether a cut-back is necessary. While some may profess a "feel" for the situation, no longer is this sufficient to convince a demanding public that restraint is necessary. Even if it were, such "feelings" have just as often proven wrong as right. The view is now widespread that a scientifically more rigorous approach is needed for the detection of overexploitation.

A problem that has plagued fisheries scientists for so long is not amenable to quick and final solution. However, it is realistic to expect that useful guidelines for application by field staff in dealing with overexploitation can emerge from a review of current knowledge. Such reasoning led to the formation of the working group (Appendix 1) to consider and recommend means by which overexploitation might be identified.

Purpose of Report

This report outlines practical means by which the severity of the fishing stress may be examined. It has two thrusts. One is to advance a line of reasoning -- in essence, to raise questions or issues that should be asked or considered in any analysis of fishing impact. The other is to specify parameters and procedures for quantifying fishing effects and some benchmarks for reference when interpreting results.

This report is not intended as a checklist which one has only to step through to arrive at a conclusion about the state of a particular fishery; the problem is far too complex to allow so simple a solution. While some thresholds for changes induced by fishing are proposed, these are better thought of as thresholds for concern, not as dividing lines between strictly safe and unsafe conditions. Decisions regarding overfishing will, in fact, be judgement decisions based on the weight of circumstantial evidence.

Definition of overexploitation

The definition of overexploitation is at the heart of this exercise. There can be more than one definition and the choice made will influence what managers should monitor and when they should act.

In the traditional sense, a state of biological overexploitation exists if the productivity of a fishery resource is diminished by the effects of fishing. The turning point under this definition is essentially the point of maximum sustained yield (MSY). In practice, the point of MSY is virtually undefinable. Arguments have been advanced for its rejection as a management objective (Larkin 1977) and for many of the same reasons we cannot realistically work with a definition of overexploitation expressed in the same terms.

In our view a working definition of overexploitation should recognize (1) that fisheries are continuously in a state of flux with a large element of unpredictability; (2) that high risk is associated with yields closely approaching the MSY; and (3) that the degree of risk is partly related to our knowledge about a situation and our capacity to respond to perceived problems. Hence, we offer the following definition:

> A fishery resource is being overexploited, if, because of fishing, yields no longer can be maintained at or near peak potential, or there is good reason to believe that the resource is predisposed to collapse or displacement.

For example, a population that has exhausted its ability to compensate could be considered unstable and in danger of collapse -- hence, overexploited. Likewise, a stock contributing high yields in some years but prone to wide fluctuations in abundance is susceptible to interspecific pressures and possible displacement when its numbers are few. It, too, might be judged overexploited.

There is an analogy in night driving that may serve to clarify the issue. A person whose speed would preclude evasive action should a hazard appear at the fringe of the illuminated field is "overdriving his headlights" -- whether or not an accident actually occurs. This analogy also highlights two determinants of risk: (1) ability to foresee danger; and (2) ability to react. The greater the illumination or the faster the driver's reaction time, the higher the safe speed.

The same principles have implications for fisheries management. In situations where the resource can be closely monitored, developing problems can be detected, and the mechanism for counteraction is in place, exploitation can be carried to a higher safe limit. Lack of information, on the other hand, is not reason for inaction, but reason for conservatism.

Overexploitation is not a simple state. At the species level, biological overfishing resulting in a reduction in yield may take either of two forms:

"recruitment overfishing" - the spawning stock is reduced by fishing to a point where recruitment (reproduction) limits yield, in some if not all years.

"growth overfishing" - heavy exploitation, usually at early ages, prevents realization of the growth (in biomass) potential of a stock or cohort with a resultant loss in yield.

Biological overfishing may also occur in a community context. This usually is caused by heavy and selective fishing applied to only a few species in the community. In more extreme cases, species being harvested experience depensatory mortality from species that are favoured by the new set of circumstances. Community overfishing thus may lead to changes in community composition which are not easily reversed by reducing or eliminating fishing pressure.

Non-biological overfishing is now widely recognized. Benefits may be dissipated if an excessive amount of effort is deployed in catching a given amount of fish. In the case of commercial fisheries, the loss is in terms of economic rent and the condition is referred to as "economic overfishing". Recreational fisheries, too, can be affected. An intensity of recreational use that reduces the individual's experience below a level of satisfaction might be termed "societal overfishing". These forms of overfishing are independent from biological overfishing and are likely to occur at a different point in the development of a fishery.

Terms of reference

Overexploitation as dealt with in this paper is in the biological sense only. This was clearly the intent of the charge set out for the working group. Mention of overfishing as it applies to socio-economic benefits is solely for the purpose of acknowledging that the term overexploitation can have different meanings, depending on the parameters chosen for study (Cunningham and Whitmarsh 1981).

Guidelines for biological overexploitation were to be those that would serve districts given the kinds of data that would currently be at their disposal or that would be within their power to collect. For this specific reason it was suggested that the group direct its efforts to single species indicators.

The initial tasks set by the group were the following:

1. List and review the responses of fish populations to exploitation.
2. Select responses likely to have practical application if defining a state of overexploitation.
3. For each response, develop criteria for assessing the severity of the stress, suggest threshold levels where possible, or describe a methodology by which threshold levels can be developed.
4. Qualify the use of each indicator.

EFFECTS OF EXPLOITATION

Exploited fish stocks undergo change (Regier and Loftus 1972, Spangler et al 1977, Francis et al 1979). Some of these changes are compensatory -- they act to increase reproduction, survival and growth and hence to offset the removal of fish from the population. This entire report is based on the proposition that the stress from exploitation can be ascertained from the degree of change (all else being equal) and that tolerance to increased fishing will be a function of the scope for additional compensation.

A list of effects of exploitation on stocks follows. It was developed from effects reported by Regier and Loftus (1972) and Spangler et al (1977) for salmonid and percid communities, respectively, but it could equally apply to any other species being exploited in Ontario.

Effects of exploitation on stocks

* - decline in abundance
* - change in yield
* - altered age composition and reduction in mean age
* - more rapid growth
* - reduced age at first maturity
* - increased variance in some parameters (e.g. recruitment)
- increase in fecundity
- change in genetic stocks
- interstock desegregation

Those parameters having the greatest potential for use as indicators are marked with an asterisk. They can be reduced into three categories: effects relating to population size; those relating to population structure; and a final group relating to physiological mechanisms. It is in the third category that most compensation occurs.

While it is not our intention to deal at length with community effects, we do feel that the better known of these should be mentioned. A listing from Francis et al (1979) is therefore included below.

Changes in species composition

- dominance shifts from high-valued to low-valued species
- dominance shifts from species that achieve large size to species that do not
- dominance shifts from species that are long lived to those that are not
- dominance shifts from benthic to pelagic species
- dominance shifts from "K selected" to "r selected" species (Appendix 2)
- dominance shifts from native to exotic species.

Henderson et al (1973) have defined three stages in the development of a fishery:

1. unexploited: fishing activity too small to significantly affect the stocks, increase in yield is a simple linear function of increase in fishing units;
2. moderate: fishing activity sufficient to produce observable changes in the size or age structure of the stocks, increase in yield is a function of both fishing units and current total yield;
3. intense: fishing activity a possible threat to recruitment of the stocks, total yield maximal or even decreasing with increase in fishing units.

We mention these stages to emphasize two points. First, it is in the third stage that potential yield is realized and that overexploitation may occur. Changes taking place in the initial two stages, especially in stage 2,

should be accepted as a normal course of events. Without a triggering of compensatory mechanisms which increase the rate of protoplasm elaboration, potential yield would not be attainable. Secondly, it will be difficult interpreting certain statistics (e.g. yield), without first making a decision on the stage of development of the fishery.

INDICATORS

Relative yield index

The comparison we wish to make is between potential yield ($\hat{y}$) and current yield (y). The simple arithmetic difference ($\hat{y} - y$) would suffice, but for consistency with SPOF Report Number 12 (Anon. 1982) we have chosen to use the ratio $y/\hat{y}$ which Adams and Olver (1977) have termed the relative yield index.

Potential yield is an estimate of the upper limit of yield that a self-renewing resource will sustain. Various indices for predicting fish yield have been developed (Ryder et al 1974, Oglesby 1977, Matuszek 1978, Hanson and Leggett 1982, Schlesinger and Regier 1982) but in Ontario the morphoedaphic index (MEI) (Ryder 1965) is likely to continue in use because of its methodological simplicity. We endorse the use of the MEI, but urge that it be used only in the proper sense -- as a first approximation of potential yield -- and with regard for the criteria for its application. We also advise that a simple precaution be taken to reduce the possibility of error. The total dissolved solid (TDS) component of the MEI is routinely determined from specific conductance measurements. A check should be made to ensure that the most recent formula (Gale and Goodchild 1982) is used for this conversion. Values in reports or files dated before 1982 are likely to require correction.

Error in a relative yield index may also arise from error in the estimation of current yield. We can only suggest that workers consider the precision of this yield estimate when interpreting a relative yield index.

When the value of the relative yield index is one, the potential yield is being realized. At values over one, the potential is being exceeded; under one, it is not being met. But interpretation of the result is not quite so simple. The relative yield index may be below one if a state of underfishing exists (insufficient fishing effort to achieve maximum yield) or if past overfishing has occurred (maximum yield has been exceeded and is no longer attainable in the short term). A relative yield index above one outwardly suggests that overfishing is occurring, but yields beyond the sustainable level may temporarily occur early in the development of some fisheries without biological productivity being undermined.[1] There is also the possibility that one or other of the yield estimates is in error.

From the foregoing two points emerge. First, yield statistics are difficult to interpret unless the stage of development of the fishery is known, at least in qualitative terms. Secondly, yield data alone, given their questionable precision, are not sufficient to rule on the state of a fishery. Other indicators should also be examined.

The first point above raises no major obstacle. Fishing effort, yield and fish abundance follow a progression as a fishery develops (Table 1) and when examined together these descriptors should reveal how far the fishery has advanced.

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[1] While this may be so, extremely high yields early in the development of a fishery should be cause for concern. The danger is that the stock will be decimated before compensatory mechanisms have time to greatly influence biomass production. The collapse of the chub (Coregonus hoyi) stock in southern Georgian Bay after only a decade of fishing is a case in point.

Table 1. Relationship between yield, fishing effort and fish abundance during stages in the development of a fishery.

YIELD	FISHING EFFORT	ABUNDANCE	STAGE OF DEVELOPMENT
low	low	high	very early stage
intermediate	low	high	early stage
intermediate	intermediate	intermediate	early intermediate
high	high	intermediate	late intermediate
high	high	highly variable	heavily stressed
intermediate	high	low	recently overstressed
low	low	low	late stage of overexploitation

The actual yield from a lake is a function of the lake's potential and fishing pressure. An equation to predict yield from these two variables has been computed by A. McCombie (pers. comm.) using yield statistics for summer angling fisheries. This is plotted in Figure 1 for MEI's up to 130 and for intervals of angling pressure between 5 and 90 man-hr $ha^{-1}yr^{-1}$. The potential yield curve based on the MEI is incorporated in the figure as a reference line. One might expect the curves corresponding with the higher fishing pressures to be more hyberbolic in shape and future refinements may prove this to be the case. Nevertheless, as it stands the equation accounts for roughly 74% of the variation in yield.

We are proposing that Figure 1 be used in instances where only fishing pressure is known to establish the <u>likelihood</u> that the potential yield is being exceeded. It is a low resolution approach, but one that makes use of available information.

The significance of Figure 1 as a management guideline may be lost in the case of lakes with a potential yield much less than 1.0 kg $ha^{-1}yr^{-1}$. Combinations of pressure and catch-per-unit effort (CUE) leading to specific yields are shown in Figure 2. At the low potential yields indicated above, catch rates associated with fishing pressure over 10 man-hr $ha^{-1}yr^{-1}$ are unlikely to remain attractive to anglers.

Abundance

Past declarations of overexploitation have been largely predicated on abundance changes. Abundance ranks among the more important indicators, but natural fluctuation to which fish populations are prone will create a background against which fishing effects are sometimes difficult to discern.

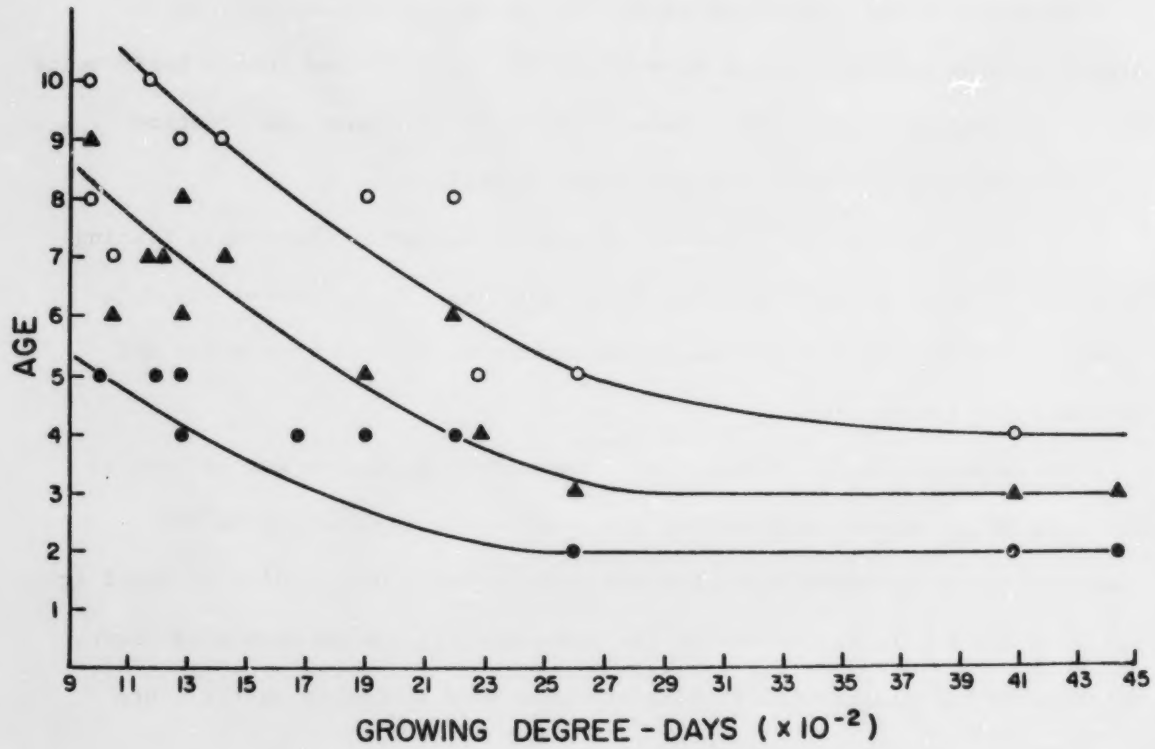


FIGURE 12: Relationship between age at maturity of female walleyes and growing season length, expressed as growring degree-days above 5°C. Plotted are the first age at which mature females appear in populations (●); the first ages at which 50% or more are mature (▲); and the first age at which all surviving females are mature (○). The data (Appendix 4) are from Colby and Nepszy (1981).

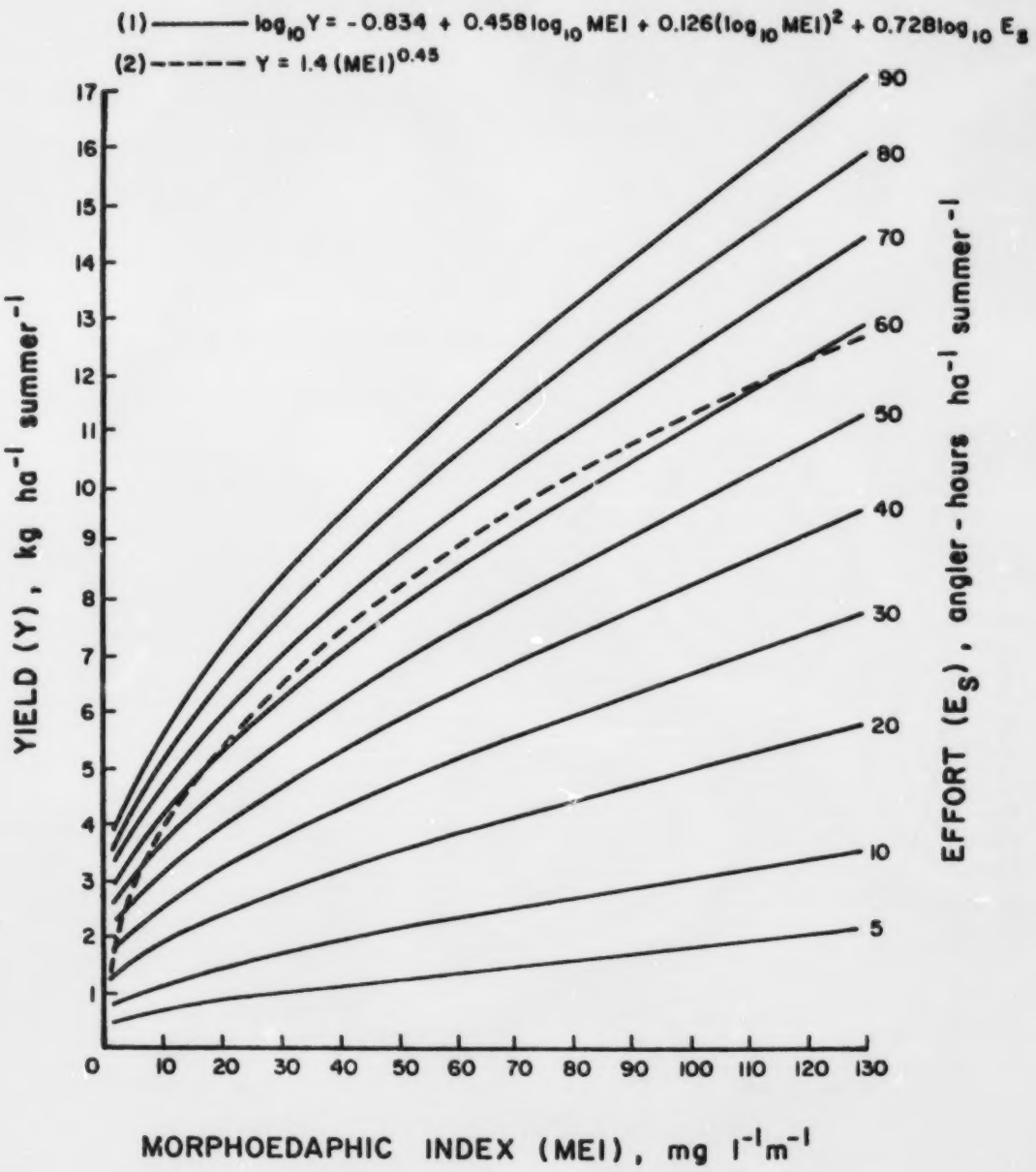


FIGURE 1: Relation between summer yields of all species combined to all anglers and the MEI, at increasing levels of summer effort. Data for the solid lines were calculated from Equation (1). The interrupted line represents potential yield values calculated for successive MEI values from Ryder's formula (Equation (2)). Figure from McCombie, 1981.

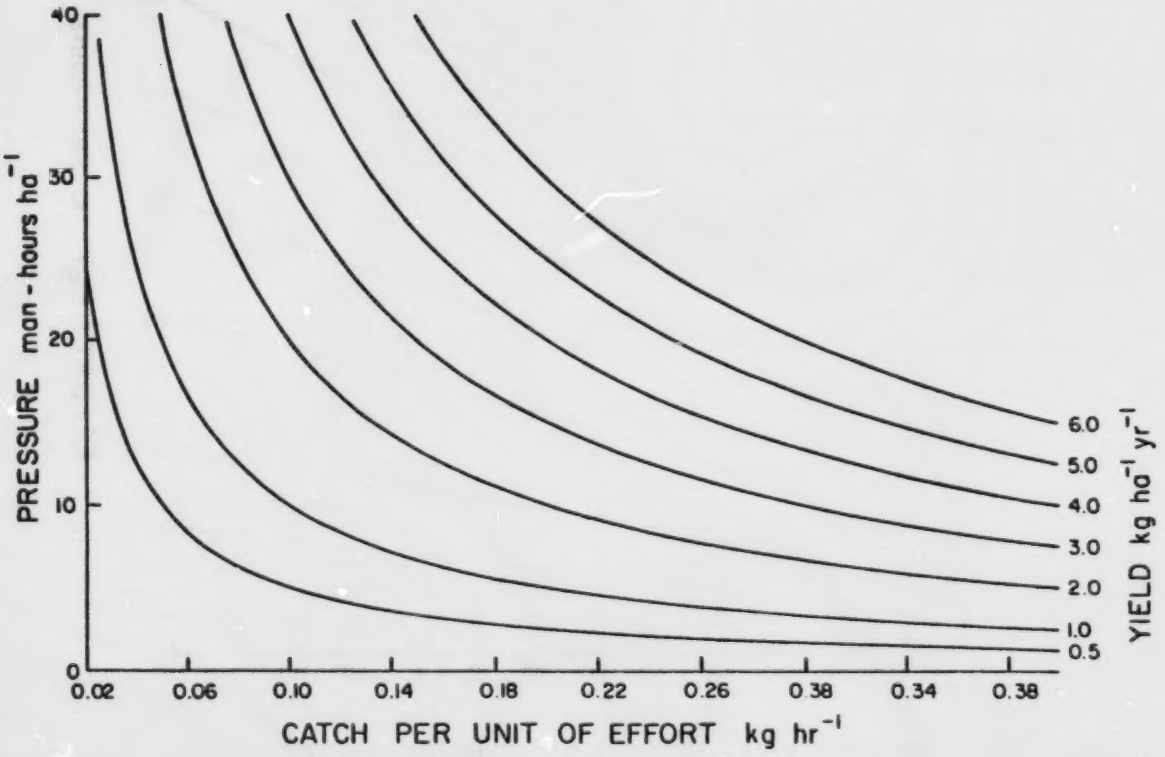


FIGURE 2: Nomogram showing the combinations of catch-per-unit of effort (CUE) and fishing pressure leading to various yields from 0.5 to 6.0 kg ha^{-1}.

There are four potential approaches to the use of abundance as an indicator.

The first involves a comparison of current abundance with some previous baseline condition. Historical information for the lake or population in question is required and it is better if it represents a post fishing-up period of "stability". Quantitative information is desirable, but if that is missing qualitative information may be substituted, if from credible sources. Because of the low resolution, a comparison using qualitative information may only reveal overexploitation in an advanced state. Even with quantitative information, this traditional approach offers only *a posteriori* proof of overexploitation.

Across lake comparisons of abundance are an alternative, but not a current one. Frequency distributions for standardized abundance indices across type lakes would have to be developed. Available data are lacking in the necessary standardization, documentation, quality and quantity, but this deficiency should be overcome as long-term data sets are created for assessment lakes.

Trend analysis is the third approach and the approach frequently leading to misinterpretation. The common fault is the selection of too short a time span for analysis. It is normal for populations to fluctuate under the influence of environmental factors beyond human control. The period of oscillation is variable and may, in some cases, be several years. This opens the possibility that a single leg, either upward or downward, may be mistaken for a trend. Trend analysis is not likely to be meaningful if the period of observation is less than <u>one generation time</u> and a still longer period is much to be preferred.

Abundance may also be examined in terms of its variability. The range over which abundance varies between years tends to increase as fishermen

bring greater pressure to bear on a stock. Because this effect is visible before productivity begins to erode, it offers a better early warning mechanism than trend analysis.

Variation in annual abundance, expressed as the coefficient of variation (standard deviation as a fraction of the sample mean), has been determined for a number of species and stocks for which data series are available (Table 2). Walleye (*Stizostedion vitreum vitreum*) stocks designated as being overexploited have coefficients of variation above 0.4; those not so designated have coefficients falling mainly within the range 0.3 - 0.4. Lake whitefish (*Coregonus clupeaformis*) appear similar. The lake trout (*Salvelinus namaycush*) stocks listed, none of which are said to be overfished, have coefficients ranging from 0.21 - 0.36. The limited data available for northern pike (*Esox lucius*) and smallmouth bass (*Miscropterus dolomieui*) suggest that coefficients between 0.4 and 0.5 may be normal. On the basis of the strong correlation between year-class strength in smallmouth bass and summer temperature, a wide natural fluctuation in bass abundance in the Ontario portion of its range is to be expected.

For the present, we suggest the following coefficients of variation in abundance as thresholds for concern:

lake trout	0.35
walleye, lake whitefish	0.40
northern pike	0.45
smallmouth bass	0.50

In most cases, abundance will be known only in relative terms, CUE serving as the index. Use of CUE in this sense has been questioned for recreational fisheries where capture depends on a feeding response (Spangler et al 1977). However, where gross change has occurred, it is unlikely that a manager's perception of a sport fishery will be altered if differences in the catchability of the fish are ignored. Corrections to CUE data should be

Table 2. Coefficients of variation ($s/\bar{x}$) determined from annual abundance indices for the species, lakes and periods listed.

SPECIES	LAKE	DATA TYPE	PERIOD	COEFFICIENT OF VARIATION	COMMENT	SOURCE
walleye	Erie	CUE-gillnet	1948-61	0.73	overexploited	Regier et al (1969)
		CUE-trapnet	1948-61	0.63	overexploited	Regier et al (1969)
	Rainy	CUE-gillnet	1949-79	0.46	overexploited-recovering	Osborn et al (1981)
	St. Clair	CUE-angling	1969-75	0.35	"remained strong"	Johnston (1977)
	Escanaba	pop'n estimates	1955-72	0.36	relatively stable	Kempinger & Carline (1977)
	Nipigon	CUE-gillnets	1954-65	0.52	pollution stress	Ryder (1968)
	Lac Des Mille Lac	CUE-angling	1958-75	0.57	fishing-up-earlier years	Elsey & Thomson (1977)
lake trout	Basswood	CUE-angling	1967-80	0.31		Purych (pers. comm.)
	Chiblow	CUE-angling	1967-79	0.22		Purych (pers. comm.)
	Semiwhite	CUE-angling	1968-79	0.21		Purych (pers. comm.)
	Bone	CUE-angling	1968-79	0.36	very high yields	France-Bernier
northern Pike	Nipissing	CUE-angling	1960-75	0.38		
	Rainy	CUE-exp.gillnet	1970-80	0.42	"fairly stable"	Osborn et al (1981)
whitefish	Georgian Bay	CUE-gillnet	1948-64	0.32	heavy fishing	Cucin & Regier (1966)
	Ontario	virtul pop'n	1943-56	0.48	overfished	Christie (1963)
smallmouth bass	Huron-Baie du Doré	CUE-angling	1963-81	0.44	improving	Wismer & Regier (1982)

made in the case of commercial fisheries where technological change has produced measureable improvements in gear efficiency.

Age structure

The age structure of a population is a function of recruitment and the subsequent survival of recruits. Unfished populations tend toward a climax state in which large, old individuals dominate and few progeny survive through juvenile life (Johnson 1972). This state cannot persist in the face of fishing and should not be regarded as the baseline to which a fishery should be returned.

Exploitation affects both recruitment and survival. The effect on survival is direct, immediate and depressive. The preference of fisheries for larger fish also means that the effect typically is applied to the older age classes. The effect on recruitment is indirect and delayed and the direction of the effect can change depending on the stage of development of the fishery. In the early stages of a fishery the reduction in abundance from the initial high level reduces intraspecific competition and increases the likelihood of larval and juvenile fish surviving and recruiting into the fishery in greater numbers. Hence, recruitment can be enhanced. Eventually, if fishing pressure becomes intensive, the spawning stock can be diminished to the point where it limits recruitment and yield.

Three statistics may be derived from age structure data which are particularly useful in assessing the stress on a population. These are the rate of total mortality, mean age, and relative year class strength. The first two are related and represent sensitive properties.

Total mortality

From the standpoint of stock dynamics, total mortality is of greater importance than mortality attributable to fishing alone. For this reason, and because total mortality is comparatively easy to measure, total mortality is preferred over other mortality rates as an indicator. The relative contributions of fishing and natural causes to total deaths will, however, be important in deciding how much risk to take and in predicting the outcome of any new control.

The impact of different total mortality rates on a population can be seen in Figure 3. At rates of mortality much over 50% per year, fewer than 2 fish in 10 will survive an additional 2 years. Even at a more modest rate of 40% per year, only 20% of all fish can be expected to survive over a period of 3 years. There is a simple message here. If significant numbers of old fish appear in catches it is unlikely that total mortality is high or that fishing threatens the stock. Declining abundance, coupled with an age structure tending toward old fish, is usually symptomatic of a recruitment problem linked to environmental conditions.

High total mortalities entail high risk of instability or collapse. Limits where overexploitation may be said to occur for different species are not easily defined. In arriving at a set of guidelines, we have relied heavily on the opinions of researchers whose efforts and interests have been concentrated on a particular species. Some of these viewpoints are published, others we have obtained through personal communication.

Levels of total mortality beyond which managers are advised to be wary of the risk are given in Figure 4 (solid circles). These are arrayed according to the natural mortality rate generally associated with the species, as indicated by source persons or material. It was hypothesized that tolerance to high mortality would be related to the natural mortality rate to which a species is adapted. The arrangement of points tends to

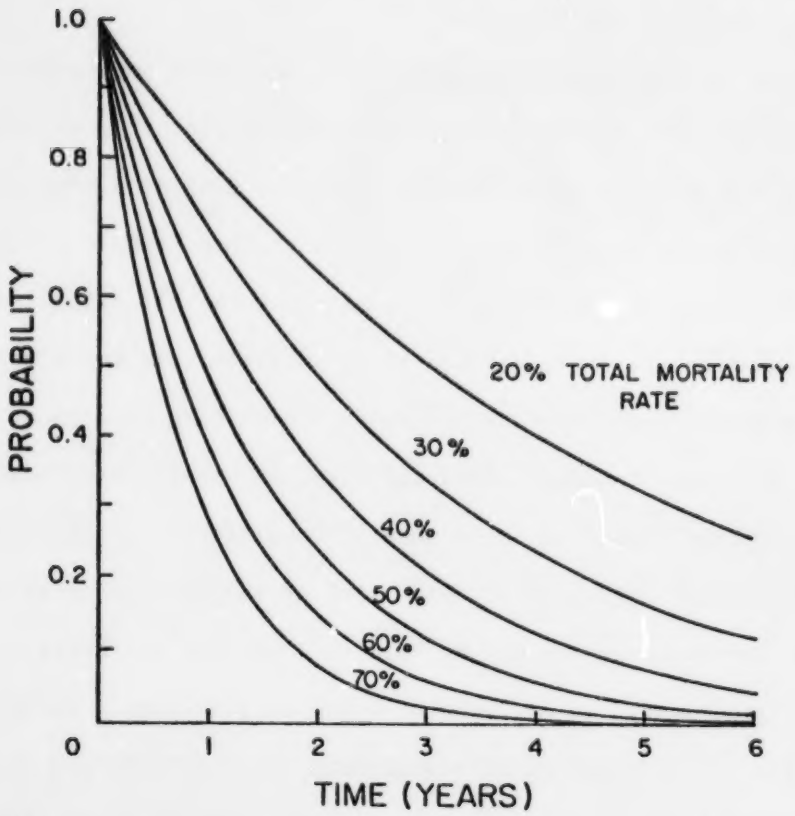


FIGURE 3: Probabilities of survival associated with annual (total) mortality rates ranging from 20% to 70%.

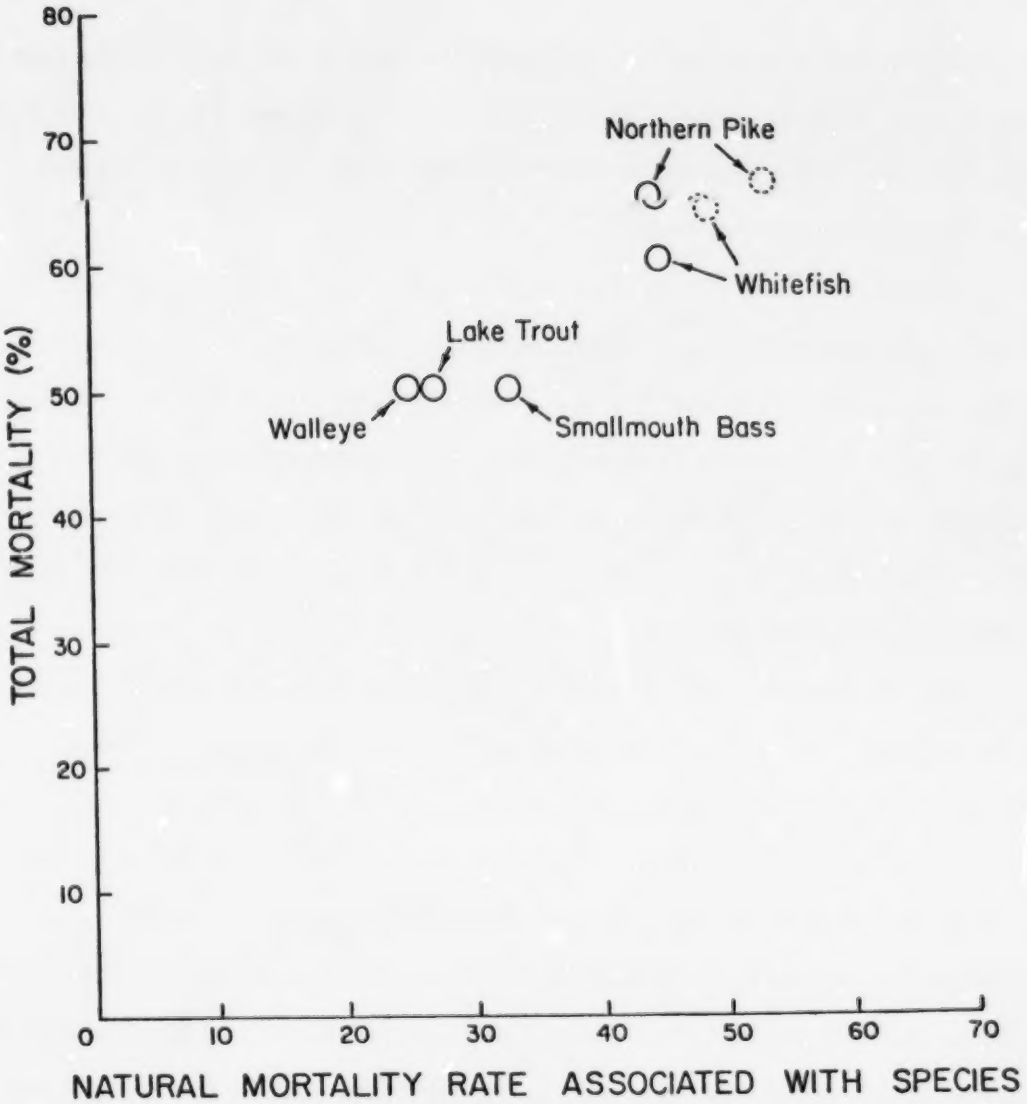


FIGURE 4: Total mortality rates (A) bordering on high risk, arrayed according to the natural mortality rate (n) generally associated with the species. Closed circles represent viewpoints of experienced researchers. Broken circles represent observed averages across sets of waters. Symbols are from Ricker (1975).

Information Sources:

walleye		(A) P. Colby (pers. comm.)
		(n) Colby et al. (1979)
lake trout		(A) Healey (1978)
		(n) Martin and Olver (1980)
smallmouth bass		(A,n) J. MacLean (pers. comm.)
whitefish	O	(A,n) J. Collins (pers. comm.)
	◌	(A,n) Healey (1975)
pike	O	(A,n) J. Casselman (pers. comm.)
	◌	(A,n) Snow (1975)

bear this out, but the points are not true data points and we are reluctant to fit a line, even by sight. The broken circles represent average conditions, across sets of populations which have been the object of study or review. They are included for comparison.

It is stressed that Figure 4 is only a guideline. Populations will have different sensitivities to total mortality depending on energy and nutrient regimes, habitat quality and community structure. As well, wide variation has been observed in natural mortality rates among populations of a single species for somewhat the same reasons. If habitat is known to be marginal or degraded, it would be better to opt for total mortality rate 5 - 10% below levels indicated.

Ricker (1975) describes methods for estimating mortality and discusses sources of bias. It is not our wish to delve into this area, but comment on estimates produced by catch curve analysis would seem appropriate. In the case of sport and commercial gillnet fisheries, mortality estimates from catch curves are generally overestimates because of decreasing vulnerability with age. In gillnet fisheries net selection is responsible. Reduced susceptibility of older fish to capture in sport fisheries is more often the result of spatial segregation of age classes or selective angling techniques. On the other hand, mortality estimates from catches out of gillnet gangs having graded mesh sizes are apt to be underestimates. Hamley and Regier (1973) found that larger meshes captured walleye more efficiently and there are theoretical reasons for believing the same may be true for other species having a wide range in size.

Mean age of the catch

Standing alone, mean age of the catch has served as a measure of the average length of time that fish remain in a population; together with mean

age at first maturity, it has been used to quantify the spawning opportunities afforded to an "average" fish in the fishery.

Both uses involve the assumption that catchability is relatively constant through time beyond the age of entry to the fishery. Herein lies the principal weakness of the indicator -- too often this assumption fails. For reasons of spatial or temporal segregation, feeding behaviour, or gear specificity, larger/older members of a stock frequently are not caught in proportion to their numbers. The picture may be further distorted if the sample upon which the mean age is based fails to accurately represent the entire catch.

As an example of the potential for problems, both in sampling and in interpretation, some mean age statistics for samples of walleye taken from the Bay of Quinte by different methods and at different times of the year are presented in Table 3. Samples taken with trapnets, experimental gillnets and by angling differed in mean age by as much as two years. Some of this difference was to be expected. Less expected were the differences among sampling periods within the year. These differences were 2.4 fold for experimental gillnets, much more than between years differences for this same gear type. In the case of angler-caught fish, within year differences were roughly equivalent in scale to between year differences. Under such circumstances, mean age becomes very sensitive to the time when fishing is done or the sample is taken. The Bay of Quinte walleye population, which is partly migratory, may not be typical, but this example serves to illustrate the need for <u>representative sampling</u> and <u>caution</u> when interpreting mean age statistics from a single source like an angling fishery.

Both recruitment and mortality affect mean age of the catch. Of the two factors, recruitment tends to be the more variable and to produce the greatest, short-term changes in mean age. This should be recognized

TABLE 3. Mean age statistics for Bay of Quinte walleye showing gear and seasonal differences and the range in annual values. Fishing effort was moderate and survival high during the period of observation.

GEAR	PERIOD	MEAN AGE	RANGE	SAMPLE SIZES
Trapnets	1957 - 63 (spring-fall)	5.4 [1]	4.6 - 6.5	331 - 1829
Experimental Gillnets	1958 - 62	3.6	2.7 - 4.8	231 - 604
	Jan - Mar	6.5 [2]		336
	Apr - Jun	3.8		465
	Jul - Sep	2.7		942
Angling	1957 - 62	3.2	2.6 - 3.5	325 - 917
	May	3.7 [2]		860
	Jun	2.9		674
	Jul	2.9		917
	Aug	3.8		802
	Sep	3.7		190

[1] The average of annual mean values.

[2] The mean age of combined samples.

intuitively, but seldom is. Consequently, changes in mean age resulting from fluctuating year-class strength too often are misread as responses to spontaneous or legislated alterations in fishing pressure.

Computer simulation allows mean age to be examined under different recruitment and mortality regimes. In two scenarios, one with a constant total mortality of 0.45 and recruitment fluctuating randomly over a threefold range, and one with mortality fluctuating randomly between 0.3 and 0.6 and recruitment held constant, similar mean ages were produced. However, over a twenty year simulation period, the range in mean age was 1.8 times greater and the variance 7.6 times greater in the case of fluctuating recruitment. In reality, recruitment tends to be more variable and mortality less variable than in these examples.

When a true change in total mortality does occur, the effect on mean age may be quite subtle. In a simulated fishery, with recruitment held constant, an abrupt decline in the total mortality rate from 0.6 to 0.3 produced a change in mean age of 0.5 years. This change took four years to complete and the largest between year change was only 0.2 years.

With fluctuating year-class strength accounting for much of the observed variability in the mean age of annual catches, it will take either long-term data series and trend analysis, or an accurate accounting of recruitment changes to isolate the fishing effect.

Despite the cautionary remarks, mean age remains a valid indicator and it is our wish to draw two published applications to attention.

Colby and Nepszy (1981) arrived at minimum mean ages necessary for adequate recruitment of walleye over a range of energy conditions. We include their "crisis curve" for walleye (Figure 5) and their recommendation that the mean age of catches for various stocks be maintained above this curve.

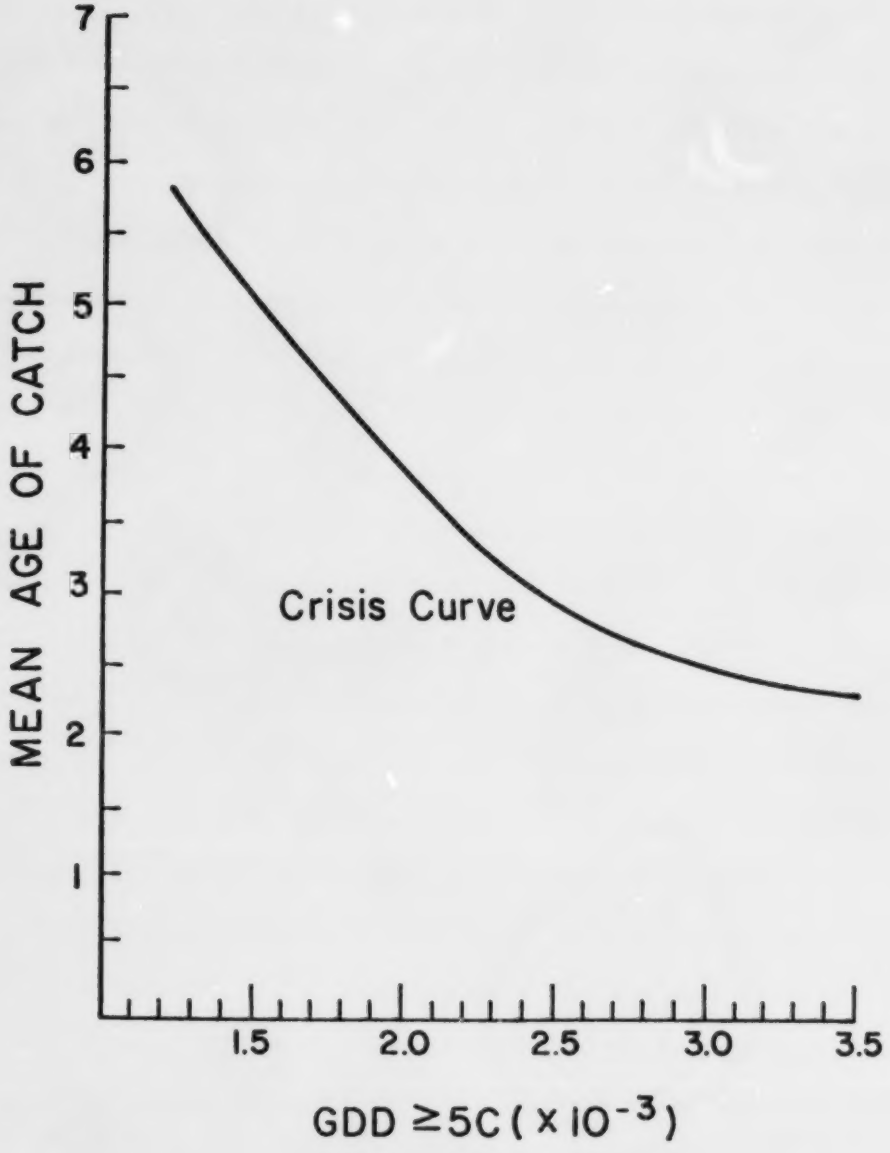


FIGURE 5: "crisis curve" - suggested relationship between the minimum scale age (weighted mean) the walleye catch can be reduced (assuming equal vulnerability of mature fish to the gear) and available energy, expressed as accumulated growing degree-days above 5^{o}, to permit adequate recruitment to perpetuate stock (after Colby and Nepszy 1981).

The second application is that by Abrosov (1969), whose "t" value (= mean age of the catch - age of onset of sexual maturity) has come to be known as the Abrosov index. "T" values consistent with high yields and stability were determined for a number of eastern European species of fish by empirical means. All recommended values were positive. No similar analysis has been done for species found in Ontario, although Christie (1972) considered 1.5 spawnings (equivalent to an Abrosov index) necessary for adequate replacement of whitefish in Lake Ontario. Experience on Lake Huron would suggest that a mean age at or near the age of first maturity is consistent with self-maintenance of whitefish where environmental conditions remain good.

The Abrosov index has been espoused because of its simplicity but that simplicity is surficial. Mean age at first maturity, as well as mean age of the catch, can change. This dual mobility along the age scale means that the index has, not one, but two dimensions to consider. The first dimension, represented by the Abrosov "t" value, measures the pressure being applied to alter time to maturity. The second dimension defines the scope for change in the maturation schedule. As mean age of the catch descends toward mean age at first maturity, pressure on the latter to drop increases. Large, positive "t" values bespeak stability and are generally viewed as safe. On the other hand, circumstances associated with small or negative "t" values auger for some departure from the current condition. This departure is apt to be a downward shift in the mean age at first maturity if the scope for such compensation remains. Population collapse is also a real possibility if the ability to compensate is exhausted. Thus, to judge nearness to the breaking point, both the strain and the deflection of the system must be examined.

In the near absence of empirically derived guideline for Ontario species, we can only speculate in a general way as to Abrosov indices

that might be appropriate. Given constant recruitment, it is easy to calculate the mean age of a population (not catch) above some age of recruitment for different total mortality rates (Figure 6). For example, with fish fully recruiting at age 3 and a constant annual mortality rate of 0.4, mean age of the exploitable population is 4.4 years (3.0 + 1.4). Judging from this, the mean age of catches from a population entering a fishery two or more years in advance of maturity will be maintained above the age of maturity only if total mortality is very low. Managing for mean ages much above the age at first maturity may, therefore, be ultra-conservative for a species regarded as tolerant of a high mortality rate (eg. 50%).

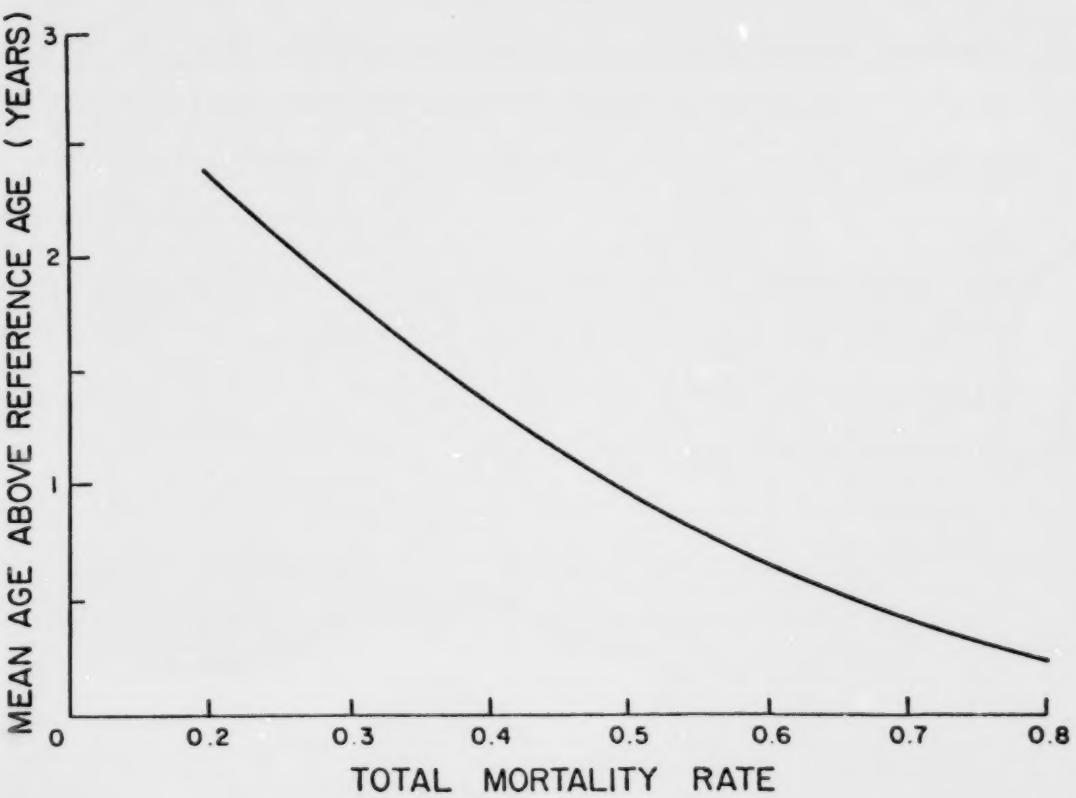


FIGURE 6: Relationship between mean age of a population and total annual mortality, each measured beyond some reference age (such as the age of entry to a fishery). If, for example, the reference age is 3.0 years and the total mortality rate is 0.5, the fish beyond the reference age will have a mean age of 3.0 + 1.0 or 4.0 years. Constant recruitment is assumed.

Variation in year-class strength

Year-class strength fluctuates widely in most natural fish populations. In North America, yellow perch year-class strength has been reported to vary from 8-fold to 40-fold, and year-class strength fluctuations in walleye of 12-fold to 74-fold have been noted (Koonce et al 1977). In the Lake Ontario whitefish fishery, recruitment varied by 22-fold over the 1943-1956 period, and the average year-class exceeded the weakest by 8 times (Christie 1963). Various factors have been implicated, with temperature emerging as one of the more dominant (Christie 1963; Koonce et al 1977; Shuter et al 1980). The evidence would indicate that year-class strength in lake trout is less variable (Martin and Olver 1980). Martin (1966) observed 2- and 4-fold differences in two piscivorous populations and 5- to 10-fold differences in two planktivorous populations.

Given the extensive natural background variation, year-class strength will have limited application as an indicator of overexploitation, especially if a variance statistic is used. More may be gained by looking for divergence of the large and small year-classes through time where a sufficiently long data series exists. Such an approach was taken by Schupp and Macins (1977), only they looked at total abundance rather than year-class abundance.

Growth

Change in growth rate of a population is one of the most sensitive indicators of change in exploitation, if environmental conditions remain constant. Increased growth has been associated with increased exploitation (Nikolsky 1963, 1965; Healey 1975, Spangler et al 1977; Chevalier 1977; Colby and Nepszy 1981). Although this response has often been reported, it is difficult to use a specific rate or even a change in a rate to detect and quantify precisely the level of exploitation. Recognizing the growth rate associated with overexploitation is even more elusive.

Many factors can interact to effect an increase in growth rate, so other corrobatory evidence should also be considered when using this indicator.

An increase in growth rate will occur if the ratio of food supply to the biomass of the species increases, either through a decrease in the abundance of the species or its competitors or through an increase in food resources. If there is no competition for food, growth will be maximal for the species under prevailing environmental conditions. The growth response to a change in food availability will be regulated by temperature and productivity.

Under certain conditions, increased exploitation of a species may result in increased biomass of the species (more individuals), and growth rate could decrease (e.g., northern pike in Heming Lake 1956-1960 (Lawler, unpublished data)).

Food consumption, rate of growth, and even spontaneous swimming activity are all directly related and are maximal at the optimum temperature for growth (e.g. northern pike, Casselman 1978).

Body growth can be both somatic and reproductive. Somatic growth can be manifested as a change in length, weight, and body condition. Although increase in weight and body condition may be more sensitive indicators of an increase in available food, change in length is most often considered.

To provide guidelines to examine linear growth in relation to exploitation, data were compiled on four species of sport fish that are frequently found in populations suspected to be overexploited -- northern pike (*Esox lucius*), walleye (*Stizostedion vitreum vitreum*), lake whitefish (*Coregonus clupeaformis*), and lake trout (*Salvelinus namaycush*). Size at age data were extracted from published papers and reports. These data were from those Ontario populations that have been most intensively studied or that were of special interest. Included are data sets from populations

that represent a wide latitudinal range. Fork length was chosen as the parameter for measuring linear growth, and the scale method of age assessment was used. The data sets used in the present compilation are provided in Appendix 3. If the data were originally expressed in total length, they were converted by using the relationships presented with the data sets. Only those data were used that indicated that the length of the fish corresponded to the length at the end of the growing season (late fall, winter, or early spring). If the samples were collected at other times of year, only those back-calculated to the annulus were used. The northern pike data (Appendix 3-1) contain 18 sets representing 12 bodies of water. The authority for each data set is listed, and the table is part of an unpublished data summary (Casselman 1981, unpublished data summary for northern pike). The walleye data (Appendix 3-2) came from specific studies and from a summary by Colby et al (1979), Gunn (1979), and Petzold (1981, OMNR unpublished data summary for walleye for SPOF Working Group No. 15). The lake whitefish data (Appendix 3-3) came from specific studies and from summaries by Healey (1975) and Ihssen et al (1981). The lake trout data (Appendix 3-4) came from specific studies as well as summaries by Healey (1978), Martin and Olver (1980), and Casselman and Petzold (1981 unpublished data summary for lake trout for SPOF Working Group No. 15).

The data were compiled to describe average size at age, growth rate, and scope for growth or growth potential for the four species within the confines of the province. The growth data show a latitudinal gradient, and are from populations with different levels of exploitation. Although additional data sets may exist and more refined data will become available, these results, although limited and presented with some reservations, provide growth standards that can be used to quantify exploitation more precisely in terms of growth.

Table 4. Means, 95% confidence limits, extremes and growth indices of fork length at scale age from 18 data sets for northern pike populations from 12 bodies of water in Ontario. The mean fork length at scale age is the growth standard. The fork length - scale age (F.L.-S.A.) growth index is the fork length expressed as a percent of the growth standard.

Assessed scale age (yr)	Growth standard		# of data sets	95% confidence limits				Range of fork lengths			
	Mean fork length (cm)	SE	N	Lower (cm)	Growth index (%)	Upper (cm)	Growth index (%)	Small-est (cm)	Growth index (%)	Larg-est (cm)	Growth index (%)
1	23.07	1.040	15	20.8	90.2	25.3	109.7	15.2	65.9	31.2	135.2
2	37.08	1.330	18	34.3	92.5	39.9	107.6	28.4	76.6	47.5	128.1
3	46.26	1.542	18	43.0	93.0	49.5	107.0	36.6	79.1	61.4	132.7
4	52.67	1.453	17	49.6	94.2	55.8	105.9	40.7	77.4	67.6	128.5
5	57.55	1.629	16	54.1	94.0	61.0	106.0	45.8	79.6	71.0	123.4
6	62.49	2.080	13	57.9	92.7	67.1	107.4	47.9	76.7	73.9	118.3
7	66.65	2.090	13	62.1	93.2	71.3	107.0	51.5	77.3	76.6	114.9
8	73.13	2.942	6	65.0	88.9	81.3	111.2	59.9	81.9	81.4	111.3
9	80.48	2.287	4					74.6		85.7	
10	84.18	2.617	4					78.5		91.3	
11	88.80	2.346	3					85.7		93.4	
12	94.15		2					91.5		96.8	
Mean					92.34		107.73		76.81		124.05

Table 5. Means, 95% confidence limits, extremes, and growth indices of fork length at scale age from 38 data sets for walleye populations from 23 bodies of water in Ontario. The mean fork length at scale age is the growth standard. The fork length - scale age (F.L.-S.A.) growth index is the fork length expressed as a percent of the growth standard.

Assessed scale age (yr)	Growth standard		# of data sets	95% confidence limits				Range of fork lengths			
	Mean fork length (cm)	SE	N	Lower (cm)	Growth index (%)	Upper (cm)	Growth index (%)	Small-est (cm)	Growth index (%)	Larg-est (cm)	Growth index (%)
1	13.43	1.168	22	11.0	81.9	15.9	118.4	7.2	53.6	22.5	167.5
2	23.55	1.207	33	21.1	89.6	26.0	110.4	11.0	46.7	33.1	140.6
3	30.29	1.422	33	27.4	90.5	33.2	109.6	18.0	59.4	41.2	136.0
4	36.15	1.380	37	33.3	92.1	39.0	107.9	22.7	62.8	53.4	147.7
5	39.56	1.391	35	36.7	92.8	42.4	107.2	27.4	69.3	54.6	138.0
6	43.15	1.415	32	40.3	93.4	46.0	106.6	29.7	68.8	59.6	138.1
7	45.87	1.419	32	43.0	93.7	48.8	106.4	35.0	76.3	61.3	133.6
8	49.50	1.418	32	46.6	94.1	52.4	105.9	37.6	76.0	64.1	129.5
9	52.48	1.452	32	49.5	94.2	55.4	105.6	39.5	75.3	66.8	127.3
10	55.40	1.564	28	52.2	94.2	58.6	105.8	43.1	77.8	68.6	123.8
11	55.08	2.076	18	50.7	92.0	59.5	108.0	43.6	79.2	67.0	121.6
12	56.06	2.356	11	50.7	90.4	61.4	109.5	46.5	82.9	72.0	128.4
13	56.62	2.826	6	48.8	86.2	64.5	113.9	49.1	86.7	69.6	122.9
14	58.33	2.764	6	50.7	86.9	66.0	113.1	54.0	92.6	71.2	122.1
15	67.80		2					63.9		71.7	
16	63.70		3					54.9		72.9	
17	62.80		3					55.6		73.2	
18	60.40		2					57.3		63.5	
Mean					90.86		109.16		71.96		134.08

Table 6. Means, 95% confidence limits, extremes, and growth indices of fork length at scale age from 15 data sets for lake whitefish populations from 11 bodies of water in Ontario. The mean fork length at scale age is the growth standard. The fork length - scale age (F.L.-S.A.) growth index is the fork length expressed as a percent of the growth standard.

Assessed scale age (yr)	Growth standard: Mean fork length (cm)	SE	# of data sets: N	95% confidence limits: Lower (cm)	Growth index (%)	Upper (cm)	Growth index (%)	Range of fork lengths: Smallest (cm)	Growth index (%)	Largest (cm)	Growth index (%)
1	12.69	1.560	12	9.2	72.5	16.2	127.7	6.9	54.4	27.9	219.9
2	18.95	1.746	14	15.1	79.7	22.3	117.7	12.2	64.4	34.9	184.2
3	25.05	2.238	15	20.2	80.6	29.9	119.4	16.3	65.1	41.8	166.9
4	29.13	2.396	15	24.0	82.4	34.3	117.7	19.4	66.6	47.3	162.4
5	32.98	2.505	15	27.6	83.7	38.4	116.4	23.2	70.3	50.4	152.8
6	35.29	2.575	15	29.7	84.2	40.9	115.9	24.5	69.4	52.6	149.1
7	36.96	2.785	15	30.9	83.6	43.0	116.3	26.5	71.7	55.6	150.4
8	38.87	2.757	15	32.9	84.6	44.8	115.3	29.3	75.4	58.0	149.2
9	41.71	2.579	15	36.1	86.5	47.3	113.4	30.7	73.6	59.6	142.9
10	42.80	2.469	14	37.4	87.4	48.2	112.6	31.8	74.3	60.9	142.3
11	46.82	2.740	13	41.9	89.5	51.8	110.6	34.4	73.5	63.3	135.2
12	46.63	2.737	11	40.4	86.6	52.8	113.2	36.1	77.4	61.5	131.9
13	48.26	2.613	11	42.3	87.7	54.2	112.3	38.1	78.9	61.0	126.4
14	49.49	2.662	9	43.1	87.1	55.8	112.8	38.8	78.4	62.3	125.9
15	49.22	3.159	6	40.5	82.3	58.0	117.8	39.5	80.3	62.6	127.2
16	49.42	4.669	4					40.5		62.3	
17	48.60		2					46.7		50.4	
18	47.60		2					46.5		48.6	
Mean					83.39		115.94		71.58		151.11

Table 7. Means, 95% confidence limits, extremes, and growth indices of fork length at scale age from 42 data sets for lake trout populations from 26 bodies of water in Ontario. The mean fork length at scale age is the growth standard. The fork length - scale age (F.L.-S.A.) growth index is the fork length expressed as a percent of the growth standard.

Assessed scale age (yr)	Growth standard		# of data sets	95% confidence limits				Range of fork lengths			
	Mean fork length (cm)	SE	N	Lower (cm)	Growth index (%)	Upper (cm)	Growth index (%)	Small-est (cm)	Growth index (%)	Larg-est (cm)	Growth index (%)
1	10.75	0.350	2								
2	18.13	1.397	10	14.9	82.2	21.4	118.0	11.4	62.9	25.4	140.1
3	22.26	0.921	18	20.4	91.6	24.2	108.7	16.1	72.3	37.2	167.1
4	27.85	1.221	33	25.4	91.2	30.3	108.8	20.3	72.9	51.3	184.2
5	32.86	1.400	39	30.0	91.3	35.7	108.6	26.4	80.3	56.9	173.2
6	39.56	1.303	38	36.9	93.3	42.2	106.7	30.4	76.8	59.7	150.9
7	45.66	1.404	32	42.8	93.7	48.5	106.2	35.5	77.7	62.9	137.8
8	51.17	1.963	27	47.1	92.0	55.2	107.9	35.6	69.6	78.7	153.8
9	56.10	1.831	23	52.3	93.2	59.8	106.6	43.9	78.3	75.6	134.8
10	60.90	1.850	19	57.0	93.6	64.8	106.4	50.1	82.3	77.5	127.3
11	66.78	2.696	16	60.9	91.2	72.6	108.7	50.8	76.1	85.0	127.3
12	70.34	2.572	14	64.7	92.0	75.9	107.9	55.4	78.8	88.5	125.8
13	74.56	3.433	8	66.2	88.8	83.0	111.3	65.4	87.7	94.0	126.1
14	76.93	2.377	6	70.3	91.4	93.5	108.5	69.8	90.7	86.7	112.7
15	77.40		3					71.6		87.6	
16	82.60		2					74.9		90.3	
Mean					91.19		108.73		77.42		143.12

Three types of growth comparisons are presented: 1) *FORK LENGTH AT SCALE AGE (F.L. - S.A.) GROWTH INDICES* similar to the type prepared by Hickley and Dexter (1979); 2) *VON BERTALANFFY GROWTH PARAMETERS* (Ricker 1975), and 3) *GROWTH PARAMETER OMEGA* (ω) calculated using $\omega = K \cdot L^{\infty}$ by Gallucci and Quinn (1979). The *GROWTH INDICES* are a measure in percent of how much a data set deviates from the *GROWTH STANDARD*, which is the mean fork length at scale age. These growth standards, the 95% confidence limits of the data sets, the extreme combining the largest and smallest fork lengths, and the growth indices are given for northern pike (Table 4), walleye (Table 5), lake whitefish (Table 6), and lake trout (Table 7). Only those ages that contain six or more data sets were used in subsequent analyses. The growth standard calculated here is slightly different than that proposed by Hickley and Dexter (1979); these standards were prepared by using mean values rather than by Walford transformation. This was necessary because a large proportion of the lake trout data could not be transformed in this fashion. The general results for these four species are illustrated in Figures 7 to 10. In addition to size at age data, growth rate is also provided using von Bertalanffy curves, equations, and growth parameters. The extreme data sets approximate the *SCOPE FOR LINEAR GROWTH* for the species in the province of Ontario.

The means, 95% confidence intervals, and extremes for asymptotic lengths (L^{∞}) and growth parameters (ω) for the individual data sets for the four species are illustrated in Figure 11.

The von Bertalanffy growth model fitted the majority of the northern pike (89%), lake whitefish (87%), and walleye (84%) data sets. However, only 26% of the lake trout data sets could be fitted by this model. This was unexpected. The mean asymptotic fork length parameters for northern pike (98.3 cm), walleye (62.3 cm), and lake whitefish (56.8 cm) are realistic. However, the mean asymptotic fork length of 145.3 cm for

Figure 7. Mean length at scale age, growth rate, and "scope for linear growth" for northern pike. Prepared from 18 sets of Ontario data. Mean fork length (cm) at assigned scale age (yr) is plotted with the number of contributing data sets indicated below. The 95% confidence limites are illustrated for ages containing six or more data sets and are joined, delineating the 95% confidence interval illustrated by the dark shaded band. The smallest and largest data set for each age are illustrated by crossbars on the vertical range lines. Lines joining these crossbars (and light shaded bands) delineate the population "scope for linear growth" for the species. The mean fork length values for each age are provided. The von Bertalanffy growth equation for the mean data is given and the curve is illustrated over the range of ages used in the calculation (ages 1 to 8). The mean ω (14.27) for Ontario northern pike is given where $\omega = k.L_\infty$ and corresponds to the growth rate near t_0 (Gallucci and Quinn 1979) and was calculated using the von Bertalanffy growth parameter k (0.145) and the asymptotic length parameter L_∞ (98.31).

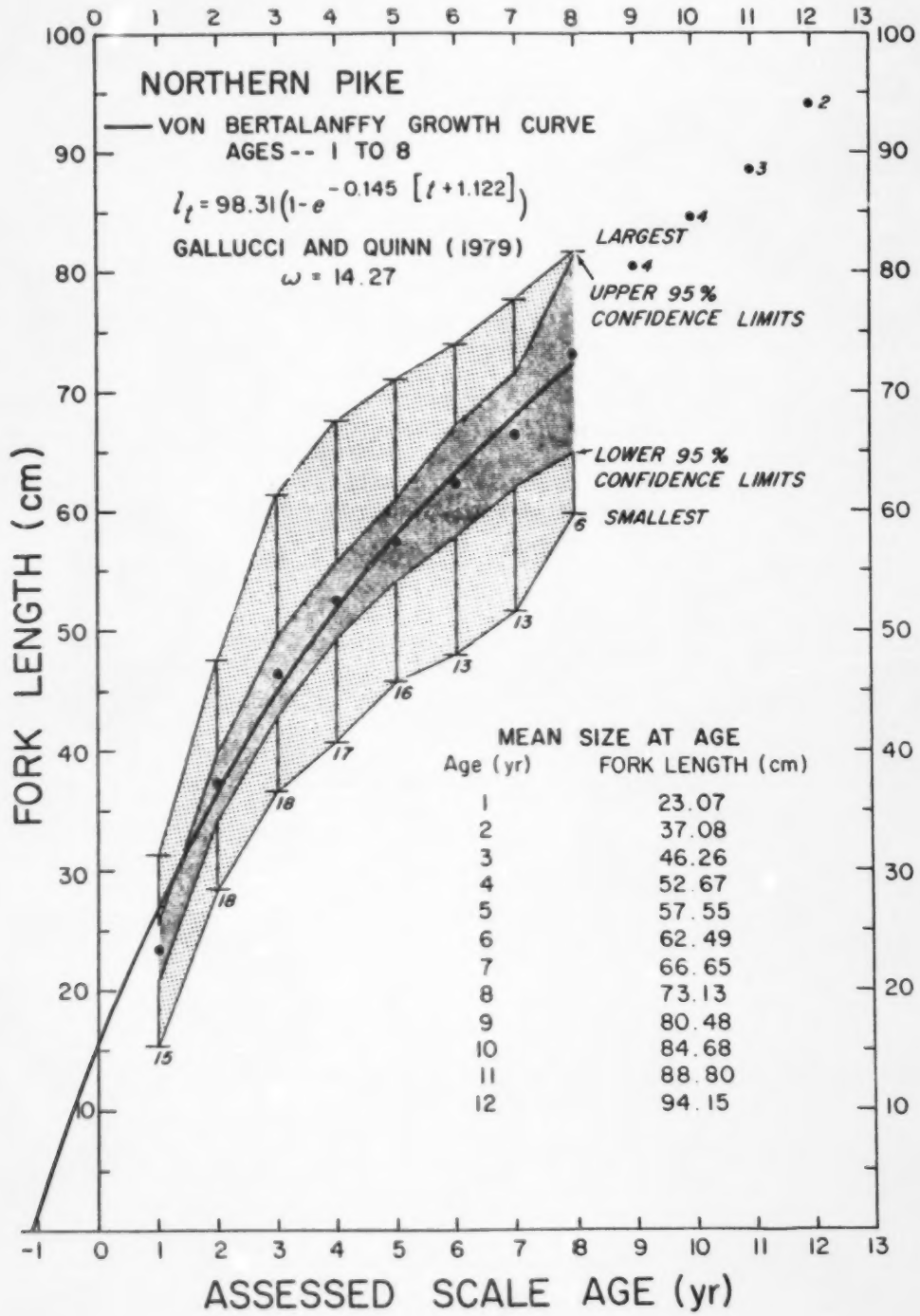

NORTHERN PIKE
VON BERTALANFFY GROWTH CURVE
AGES -- 1 TO 8
$l_t = 98.31\left(1-e^{-0.145\ [t+1.122]}\right)$
GALLUCCI AND QUINN (1979)
$\omega = 14.27$
LARGEST
UPPER 95% CONFIDENCE LIMITS
LOWER 95% CONFIDENCE LIMITS
SMALLEST
MEAN SIZE AT AGE
Age (yr) FORK LENGTH (cm)
1 23.07
2 37.08
3 46.26
4 52.67
5 57.55
6 62.49
7 66.65
8 73.13
9 80.48
10 84.68
11 88.80
12 94.15
FORK LENGTH (cm)
ASSESSED SCALE AGE (yr)

Figure 7

Figure 8. Mean length at scale age, growth rate, and "scope for linear growth" for walleye. Prepared from 38 sets of Ontario data. Mean fork length (cm) at assigned scale age (yr) is plotted with the number of contributing data sets indicated below. The 95% confidence limits are illustrated for ages containing six or more data sets and are joined, delineating the 95% confidence interval illustrated by the dark shaded band. The smallest and largest data set for each age are illustrated by crossbars on the vertical range lines. Lines joining these crossbars (and light shaded bands) delineate the population "scope for linear growth" for the species. The mean fork length values for each age are provided. The von Bertalanffy growth equation for the mean data is given and the curve is illustrated over the range of ages used in the calculation (ages 1 to 14). The mean ω (11.83) for Ontario walleye is given where $\omega = k \cdot L\infty$ and corresponds to the growth rate near t_0 (Gallucci and Quinn 1979) and was calculated by using the von Bertalanffy growth parameter k (0.191) and the asymptotic length parameter L_∞ (62.15).

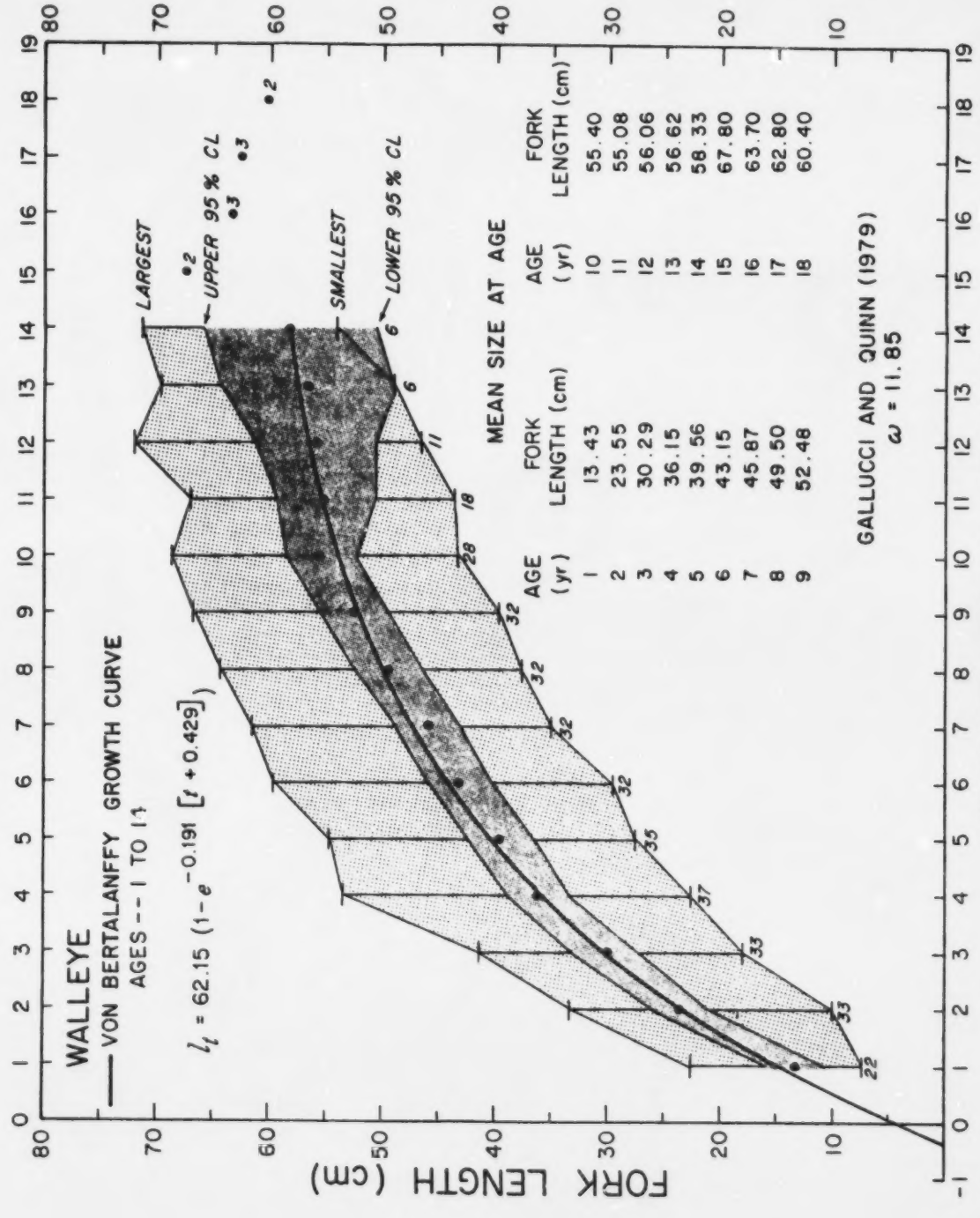

WALLEYE
VON BERTALANFFY GROWTH CURVE
AGES -- 1 TO 11
$l_t = 62.15\ (1-e^{-0.191\ [t\ +\ 0.429]})$
LARGEST
UPPER 95 % CL
SMALLEST
LOWER 95 % CL
MEAN SIZE AT AGE
AGE (yr) | FORK LENGTH (cm) | AGE (yr) | FORK LENGTH (cm)
1 | 13.43 | 10 | 55.40
2 | 23.55 | 11 | 55.08
3 | 30.29 | 12 | 56.06
4 | 36.15 | 13 | 56.62
5 | 39.56 | 14 | 58.33
6 | 43.15 | 15 | 67.80
7 | 45.87 | 16 | 63.70
8 | 49.50 | 17 | 62.80
9 | 52.48 | 18 | 60.40
GALLUCCI AND QUINN (1979)
$\omega = 11.85$
FORK LENGTH (cm)
ASSESSED SCALE AGE (yr)

Figure 8

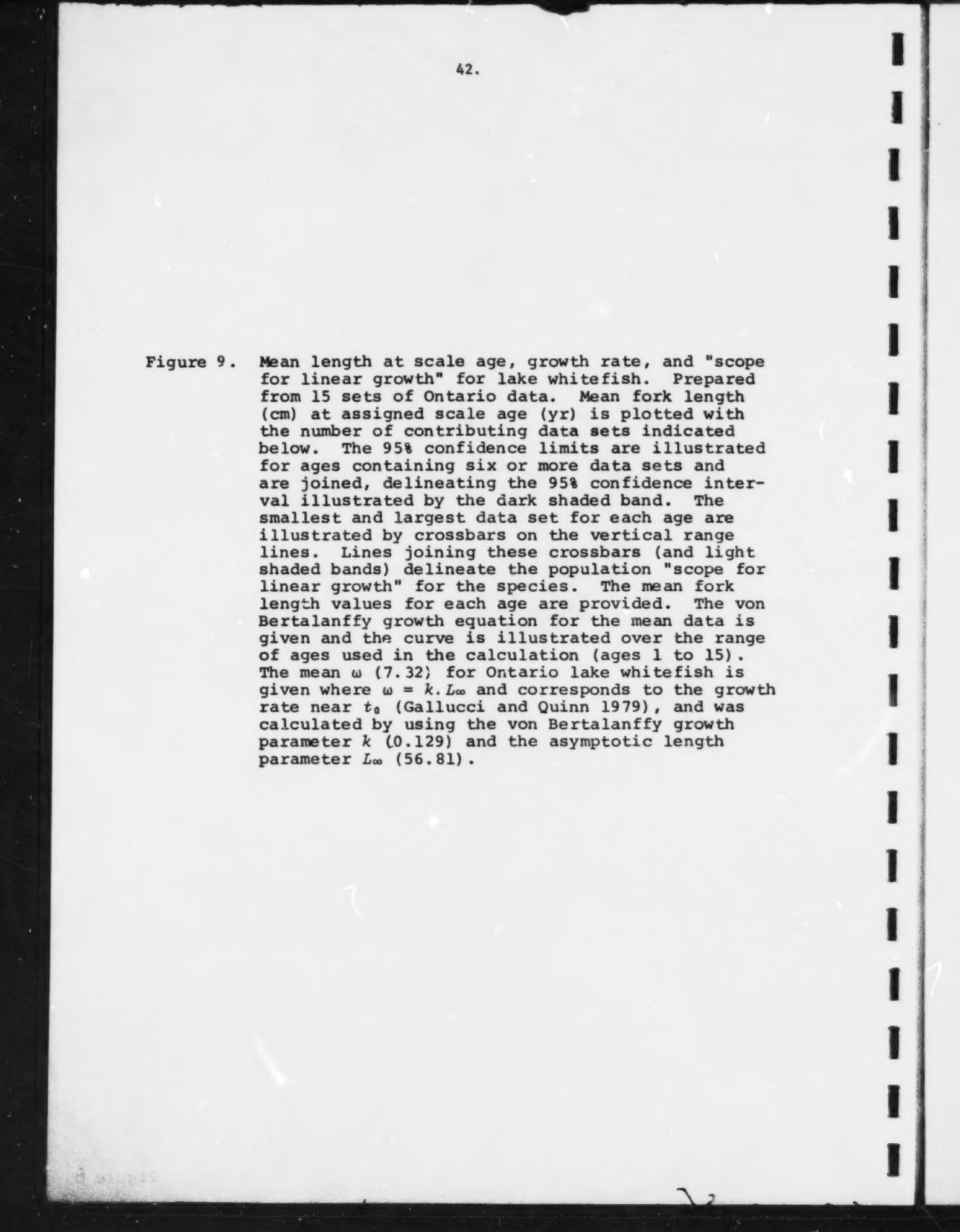
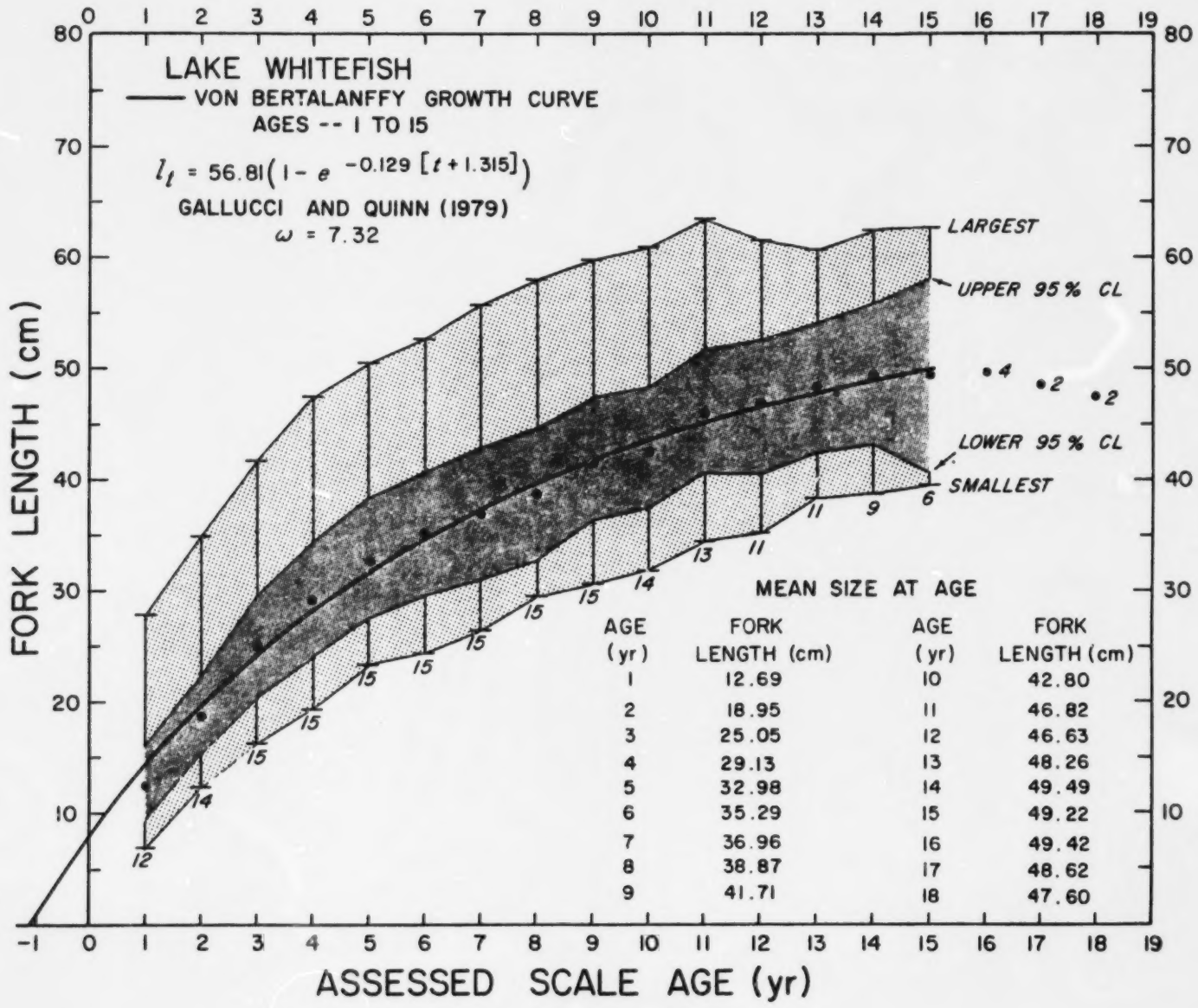


Figure 9. Mean length at scale age, growth rate, and "scope for linear growth" for lake whitefish. Prepared from 15 sets of Ontario data. Mean fork length (cm) at assigned scale age (yr) is plotted with the number of contributing data sets indicated below. The 95% confidence limits are illustrated for ages containing six or more data sets and are joined, delineating the 95% confidence interval illustrated by the dark shaded band. The smallest and largest data set for each age are illustrated by crossbars on the vertical range lines. Lines joining these crossbars (and light shaded bands) delineate the population "scope for linear growth" for the species. The mean fork length values for each age are provided. The von Bertalanffy growth equation for the mean data is given and the curve is illustrated over the range of ages used in the calculation (ages 1 to 15). The mean ω (7.32) for Ontario lake whitefish is given where $\omega = k.L_\infty$ and corresponds to the growth rate near t_0 (Gallucci and Quinn 1979), and was calculated by using the von Bertalanffy growth parameter k (0.129) and the asymptotic length parameter L_∞ (56.81).



MEAN SIZE AT AGE

AGE (yr)	FORK LENGTH (cm)	AGE (yr)	FORK LENGTH (cm)
1	12.69	10	42.80
2	18.95	11	46.82
3	25.05	12	46.63
4	29.13	13	48.26
5	32.98	14	49.49
6	35.29	15	49.22
7	36.96	16	49.42
8	38.87	17	48.62
9	41.71	18	47.60

Figure 9

Figure 10. Mean length at scale age, growth rate, and "scope for linear growth" for lake trout. Prepared from 42 sets of Ontario data. Mean fork length (cm) at assigned scale age (yr) is plotted with the number of contributing data sets indicated below. The 95% confidence limits are illustrated for ages containing six or more data sets and are joined, delineating the 95% confidence interval illustrated by the dark shaded band. The smallest and largest data set for each age are illustrated by crossbars on the vertical range lines. Lines joining these crossbars (and light shaded bands) delineate the population "scope for linear growth" for the species. The mean fork length values for each age are provided. The von Bertalanffy growth equation for the mean data is given and the curve is illustrated over the range of ages used in the calculation (ages 3 to 14). The mean ω (8.08) for Ontario lake trout is given where $\omega = k.L_\infty$ and corresponds to the growth rate near t_0 (Gallucci and Quinn 1979), and was calculated by using the von Bertalanffy growth parameter k (0.056) and the asymptotic length parameter L_∞ (145.25).

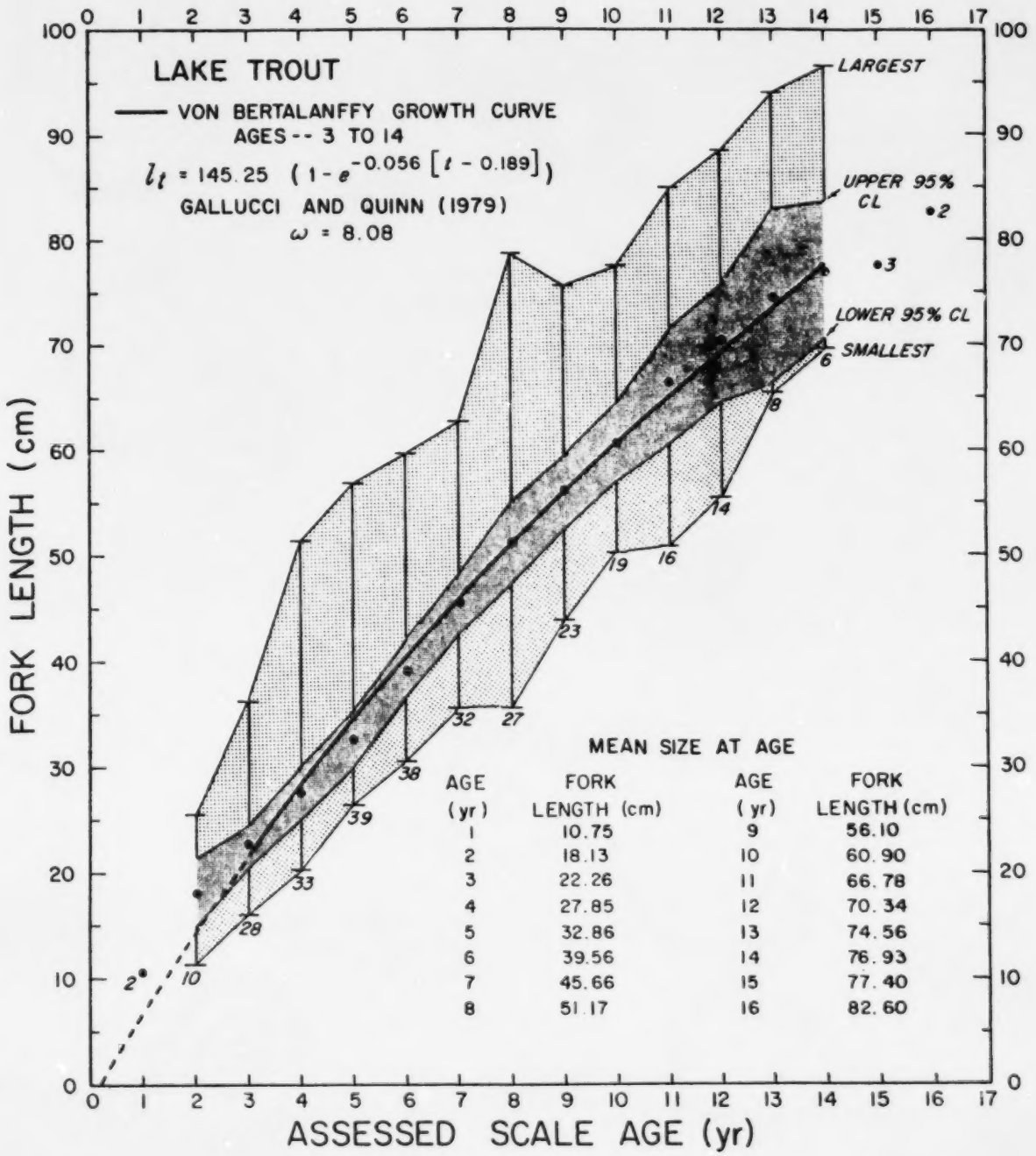

LAKE TROUT
VON BERTALANFFY GROWTH CURVE
AGES -- 3 TO 14
$l_t = 145.25\ (1 - e^{-0.056\,[t\,-\,0.189]})$
GALLUCCI AND QUINN (1979)
$\omega = 8.08$
LARGEST
UPPER 95% CL
LOWER 95% CL
SMALLEST
FORK LENGTH (cm)
ASSESSED SCALE AGE (yr)
MEAN SIZE AT AGE
AGE (yr) | FORK LENGTH (cm) | AGE (yr) | FORK LENGTH (cm)
1 | 10.75 | 9 | 56.10
2 | 18.13 | 10 | 60.90
3 | 22.26 | 11 | 66.78
4 | 27.85 | 12 | 70.34
5 | 32.86 | 13 | 74.56
6 | 39.56 | 14 | 76.93
7 | 45.66 | 15 | 77.40
8 | 51.17 | 16 | 82.60

Figure 10

Figure 11. Asymptotic lengths L_∞ (cm) and growth parameters "ω" (Gallucci and Quinn 1979) for four species of Ontario fish. Illustrates the mean and 95% confidence intervals about this mean calculated by using the standard error of the values obtained for each individual data set (northern pike, N = 16; walleye, N = 31; lake whitefish, N = 13; and lake trout, N = 10) (shaded bars) and extremes using the largest (L) and smallest (S) sizes at each age (diamond shaped symbol on horizontal range lines). The von Bertalanffy growth model did not fit the data set combining smallest sizes at age for lake trout.

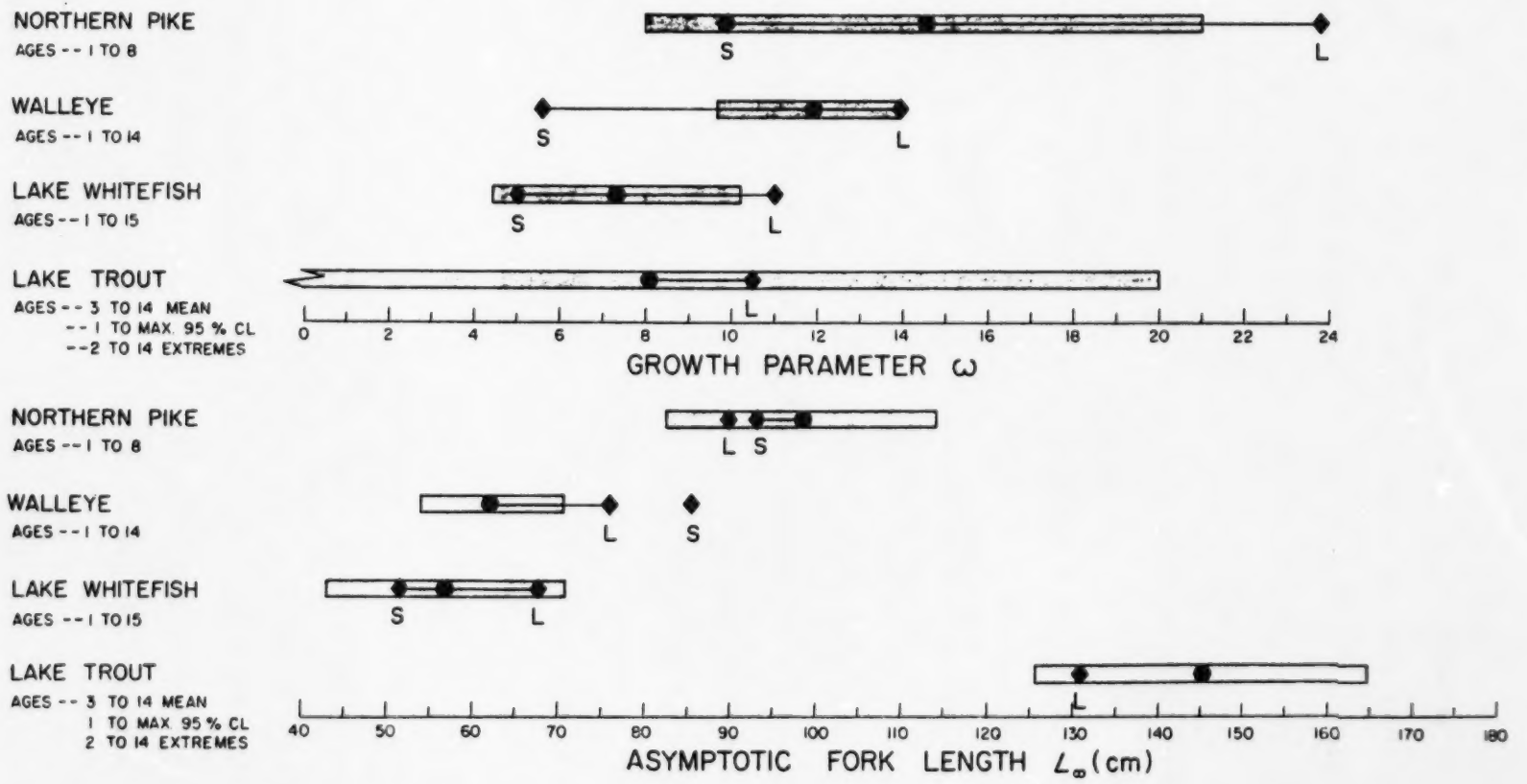

NORTHERN PIKE
AGES -- 1 TO 8
S
L
WALLEYE
AGES -- 1 TO 14
S
L
LAKE WHITEFISH
AGES -- 1 TO 15
S
L
LAKE TROUT
AGES -- 3 TO 14 MEAN
-- 1 TO MAX. 95 % CL
--2 TO 14 EXTREMES
L
0 2 4 6 8 10 12 14 16 18 20 22 24
GROWTH PARAMETER ω
NORTHERN PIKE
AGES -- 1 TO 8
L S
WALLEYE
AGES -- 1 TO 14
L
S
LAKE WHITEFISH
AGES -- 1 TO 15
S
L
LAKE TROUT
AGES -- 3 TO 14 MEAN
1 TO MAX. 95 % CL
2 TO 14 EXTREMES
L
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
ASYMPTOTIC FORK LENGTH L_∞ (cm)

Figure 11

lake trout is unrealistic, and over-estimates the maximum observed length (Martin and Olver 1980) by approximately 26%. Invalid age assessment of older lake trout could account for this abnormally large ultimate length and poor fit of the von Bertalanffy model. Considering the age range of the lake trout data, this growth model should apply. One possible explanation of these anomalies is that the scale method has failed; it is known to under-estimate the age of older individuals. The true age of lake trout from assessed scale ages of 6 to 15 may be significantly under-estimated, especially for older individuals. In a study where the assessed scale age of lake trout was corrected by verification using other calcified structures, the asymptotic length was reduced by 25% (Casselman, unpublished data). This is almost exactly the same amount (26%) by which the mean ultimate length of lake trout exceeded the observed, as reported in the published literature.

The scale method of age assessment should be treated with caution, and it should be validated or at least verified. In general, but depending to some extent upon growth rate, the scale method is inconsistent for ages 6 to 10, and for older fish may be unreliable and provide erroneous results. The scale method yields sufficiently reliable and consistent results with heavily exploited populations because they usually contain young individuals that are growing rapidly. Accurate age assessment is desirable, but consistent assessment is imperative.

Insufficient data were available to separate the growth relationships by sex. Where possible, this should be done. Caution should be taken so that differential growth rate of the sexes does not bias the results. Samples must contain either equal numbers of males and females or, as was done for the present compilation, be equally weighted by sex to obtain an unbiased average growth relationship.

In the present compilation, data sets that indicate most rapid growth were most frequently heavily exploited and most southerly in their origin. The more northerly populations had growth in the lower half of the scope, and those that were more heavily exploited grew at a rate approaching the mean. The more southerly populations had growth in the upper half of the scope, and those that were more heavily exploited grew at a rate approaching the maximum for the species in Ontario.

To quantify the relation between growth and exploitation more precisely and produce specific indices, it would be necessary to obtain these growth indices and parameters from a population or populations exposed to different levels of exploitation. It would also be necessary to include temperature and productivity of the body of water. The length of the growing season could be used to refine the temperature component. Such a procedure has been used for walleye (Colby and Nepszy 1981). With precise temperature data, the effect of departures in temperature from the optimum for growth could be taken into account. The optimum temperature for subadult and young adult fish occurs within the following ranges: northern pike -- 18 to 22C; walleye -- 21 to 25C; lake whitefish -- 11 to 15C; and lake trout -- 8 to 12 C.

The productivity of a body of water could also be used to quantify growth more precisely and refine its application in assessing the degree of exploitation. The MEI has been used in relation to growth to provide an indicator of environmental stress (Ryan and Harvey 1977).

Other factors can influence apparent growth rate. Variation can result from such factors as sampling and gear selectivity; annual climatic differences; seasonal behavioural (activity) patterns; as well as genetic, nutritional, and physiological intraspecific differences. These variations have not yet been adequately quantified; however, until more precise data are available, mean differences among indices due to these variables might be assumed to be no greater than approximately 5%.

At the present time, and until temperature and productivity can be incorporated into these growth models, the best available method of assessing exploitation in relation to a growth response is to assess the growth deviation either within or between populations, whether it be in relation to growth standards using indices or by von Bertalanffy growth parameters. Nevertheless, growth data can now be examined in relation to a mean and the scope for linear growth within a provincial context.

Age at maturity

Age at maturity, like growth, responds to density changes brought on by exploitation. Lowered densities and faster growth generally shorten the time to maturity within the limits for such compensation.

Within a population, first maturity commonly occurs over a range of ages. No single statistic adequately describes the maturation schedule, but, of those available, mean age at first maturity is considered the most descriptive. Abrosov (1969) provided a method of calculating mean weighted age of maturity. A refinement of that method by Lysack (1980) is preferred and is given below:

$$Z = \frac{A_1K_1 + A_2\,(K_2 - K_1) + A_3\,(K_3 - K_2) + \ldots + A_n\,(K_n - K_{n-1})}{K_1 + (K_2 - K_1) + (K_3 - K_2) + \ldots + (K_n - K_{n-1})}$$

where Z = mean weighted age of onset of sexual maturity

A = age (years)

K_n = % of mature fish in the n^{th} age class.

Lysack (1980) also offers an interesting, alternate means of quantifying the onset of initial maturity. It involves fitting a logistic curve to the frequency of mature fish at various ages in the following manner:

$$Y_x = \frac{k}{1 + e^{-b(x - x_o)}}$$

where Y_x = frequency of mature fish among all fish aged x

k = frequency of mature fish among the oldest age groups

x_o = age at inflection point

b = slope

It is assumed that k = 100%. To facilitate fitting a regression by least squares, the data are transformed as follows: $-\log_e (\frac{k - y}{y} + 1) = -bX_o + bX$

The method has the advantage of offering both an instantaneous maturity rate (b) and an inflection point (X) as descriptors. Either or both could change with increasing fishing pressure.

The addition of + 1 within the brackets of the linear version of the equation (to avoid $\log\infty$) has been questioned by W. Ricker (note to P. Colby). He suggests, instead, that 0% and 100% ages be ignored. Inherent in the use of a logistic curve are the assumptions that the inflection point is always at 50%; that percentages are symmetrical on either side of 50%; and, that all ages have at least a few immature and mature fish. Obviously, these will not all be met. Nevertheless, Ricker stated that the logistic curve may be the best simple curve available. We include Lysack's equations and Ricker's comments as encouragement to trial use of the method.

There is one situation in which the logistic curve is unlikely to fit the data -- namely, where growth is rapid and full maturity of females is reached in as little as two years. In such cases, the weighted average age may better represent the maturation schedule.

The schedule of initial maturation is currently one of the least well documented attributes of fish stocks. Most observations pertain to spawning runs and they reveal only the ages at which mature fish occur in a population. The percentage mature at each age, which is the more important statistic, should be determined by internal examination of fish collected at a time when there is little or no segregation of immature and mature constituents of a population. Little of this type of sampling has been done.

For many species, use of age at maturity will be limited by the paucity of good reference data with which to define the scope for change.

Colby and Nepszy (1981) present maturity data for female walleyes and relate some of the variability to growing-degree-days > $5^{o}C$ (Appendix 4). They were able to show that northern stocks mature later and over a greater

number of years than southern stocks. Using their tabulation and the same growing-degree-days axis, we have plotted the ages at which mature female walleye first appear; the ages at which 50% or more are mature; and the ages at which 100% are mature (Figure 12). The outer boundaries drawn will approximate the range of ages over which walleye are apt to be maturing for a given thermal regime. Heavily exploited walleyes might be expected to mature at ages in the lower portion of the plotted range.

Of interest is the position of the crisis curve for walleye (Figure 5) in relation to these three lines (Figure 12). On average, the crisis curve falls about one-half year below the ages at which 50% maturity usually occurs over the growing degree range. The ages at which mature female are initially observed over the range of thermal units are below the crisis curve. Obviously, the performance of a few fish does not represent the scope for compensation by an entire population.

Martin and Olver (1980) summarized the available information on age at first maturity in lake trout. Age 4 was the youngest age at which lake trout of either sex were found to mature. In Ontario and adjoining jurisdictions, it is more common for initial maturity to occur at age 5 or 6, with males maturing a year earlier than females. Full maturity seldom occurs before age 7. Our perception is that 50% or greater maturity in males at age 5 and females at age 6 represents comparatively early maturation in piscivorous lake trout populations in Ontario.

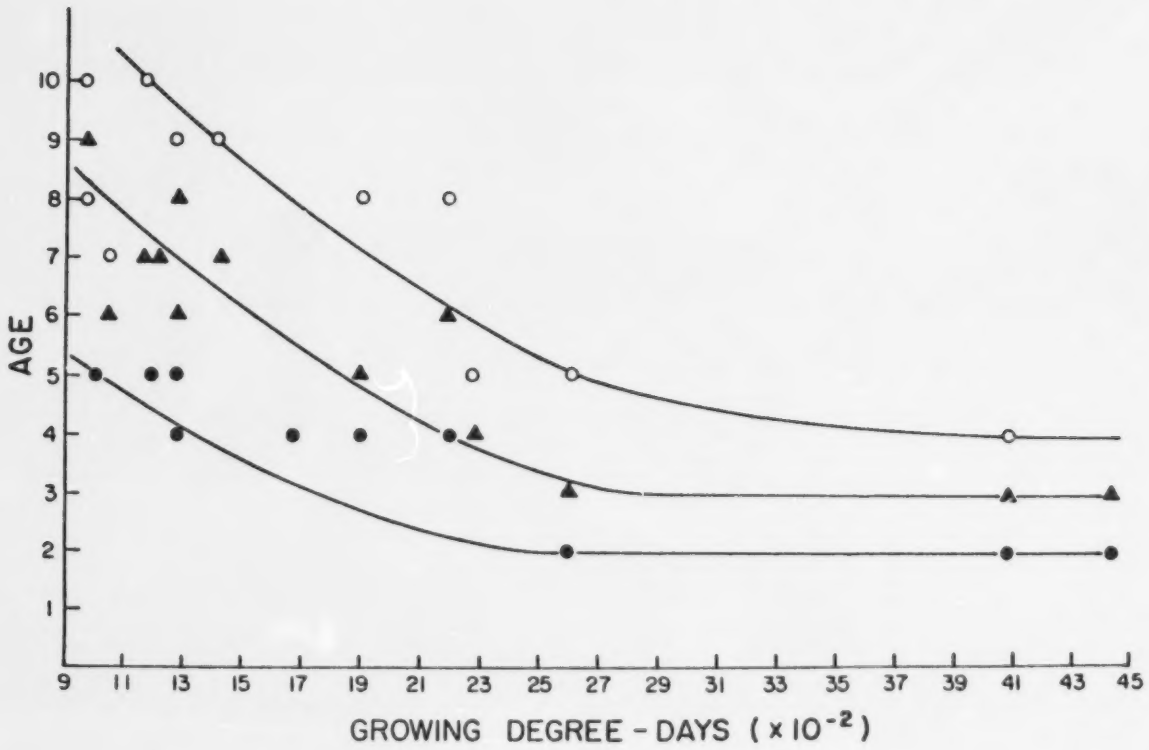


FIGURE 12: Relationship between age at maturity of female walleyes and growing season length, expressed as growring degree-days above 5°C. Plotted are the first age at which mature females appear in populations (●); the first ages at which 50% or more are mature (▲); and the first age at which all surviving females are mature (○). The data (Appendix 4) are from Colby and Nepszy (1981).

TEST APPLICATIONS

In this section we use the indicators to assess the status of fisheries on two lakes. Flack Lake, a 934 ha lake in the Blind River District, supports a fishery that is entirely for lake trout. Eagle Lake, a 27,700 ha lake in the Dryden area, has a recreational fishery centered around walleye, northern pike, maskinonge and lake trout and a commercial fishery currently based on lake whitefish. Both fisheries have been regarded as borderline cases with respect to overexploitation. Primary source documents for this review are a report on the Flack Lake fishery by Purych (1976), and reports on the Eagle Lake fisheries by Chevalier (1975) and Charles (1979). Additional limnological data on Eagle Lake was supplied by P. Ryan (pers. comm.).

Eagle Lake - data synopsis

Except for total yield statistics, this synopsis will be confined to lake whitefish, walleye and northern pike, the species that constitute the bulk of the harvest. This choice is dictated by the amount and kinds of data presently available in summarized form.

Values for total dissolved solids (TDS) ranging from 21 to 43 mg l^{-1} have been reported for Eagle Lake. The most recent interpretation of conductivity data from Eagle Lake places TDS at 26 mg l^{-1} (Anon. 1982). Given a mean depth of 6.8 m, potential yield is computed to be 2.56 kg ha^{-1} yr^{-1}.

This potential appears to have been exceeded throughout the recorded period of fishing. A relatively stable commercial fishery operating from 1924 - 30 had annual yields which, on average, met 91% of the estimated

potential. The yield by angling in those years is not known, but the allowance suggested by Charles (1979), if of the proper order, would raise the total to 125% (RYI = 1.25). More recent yields remain similar in magnitude if not in composition. For 1973 and 1979, two years when the harvest by anglers was estimated, the relative yield indices were 1.2 and 1.1, respectively. Lower fishing effort in the second of these years accounts for the difference.

There is some reason to believe that Eagle Lake may be a more productive system than its TDS would indicate. Total phosphorus levels determined from samples taken at widely distributed points throughout the lake in 1980 ranged from 8 - 33 mg m^{-3} with a mean of 19.8. This is disproportionately high (roughly an order of magnitude high) given a TDS of 26 mg l^{-1}. The observations describe a gradient in phosphorus from high in the southeast to low in the northwest, which is matched by a reverse gradient in secchi disk readings (1.1 to 5.7 m). Observed yields by angling increase along the cline defined for phosphorus. Much of the lake can be considered mesotrophic, and by one classification (Dobson *et al* 1974), the extreme southeastern portion might be judged eutrophic.

During the initial period of commercial fishing, which ended in 1941, walleye was the target species. When fishing was resumed in 1951, lake whitefish became the sought after species. This change, in part, will explain shifts in the species composition of the catch.

Table 8. Yield from Eagle Lake, by selected species, expressed as a percentage of potential yield.

PERIOD	L. WHITEFISH	N. PIKE	WALLEYE
1924 - 39[c]	15	25	36
1955 - 74[c]	34		
1973, 1979[a]		26	28

[c] commercial only

[a] by angling, but including a small commercial incidental catch

Yields of lake whitefish, northern pike and walleye, expressed as a percentage of the potential yield, are shown in Table 8. In the initial 16 year period, walleye catches remained quite stable, northern pike catches increased and whitefish catches declined. The reverse trends for northern pike and whitefish may be the result of a change in the temporal or spatial deployment of gear. Annual catches of whitefish after 1952 have remained quite stable (CV = 0.25) about a mean of 24.2 metric tons. The yield of pike has remained a relatively constant percentage of the potential yield (25%) but under an angling fishery alone the yield of walleye represents a smaller percentage (28%) than before.

Catch per unit of effort statistics have not been computed for the commercial fishery and are too few for the angling fishery to afford a time series perspective. Catch rates (CUE) for walleye and northern pike differed little between 1973 and 1979, 0.21 and 0.20 respectively for walleye, and 0.09 and 0.10 for pike, Differences across the lake within a year were substantially greater, ranging from 0.03 to 0.44 for walleye in 1973. Habitat differences would account for some of this. Excluded from the calculation of above CUEs were fish returned. This would be a

considerable fraction of the catch in the case of pike which seldom were a target species.

None of the reported total mortality rates can be classed as high. Based on catches in experimental gillnets, the total mortality rate for walleye was estimated to be 0.37 in the northern part of the lake and 0.21 in the south. Data from spawning walleye captured at Whiteclay Narrows translate into a 0.30 rate of total mortality for that spawning stock. From experimental gillnet catches, total mortality rates for northern pike and whitefish were estimated at 0.37 and 0.34, respectively. All of these rates are well below our guidelines.

Rates of first year returns of tagged walleye lend credence to the estimates of total mortality for that species. With one exception these return rates were tightly clustered around 19%. Using the 0.37 total mortality rate (A) and a 0.19 exploitation rate (u), and assuming a Ricker type 2 fishery, the conditional natural fishing mortality rate (n) works out to 0.20. This is close to the 0.25 mentioned earlier in this report as a "normal" condition.

The analysis of available growth data for Eagle Lake species has been confined to simple comparisons between sampling periods and with the Ontario average. Data were too few or varied too much in time or mode of sampling to permit any other treatment.

Two samples of lake whitefish were compared, even though the age distributions were quite different. Both growth parameters, L_∞ and ω, indicated that growth rates in 1972 - 73 and 1979 were similar and slightly above average for the species. The growth indices for these data sets provided similar results, indicating a growth rate slightly above the Ontario average (1972 - 73 -- 107.3%; 1979 -- 104.8%).

Three sets of growth data for walleye permitted a comparison. The von Bertalanffy growth model did not fit the 1972 - 73 sample, so only size

at age comparisons could be made. Two independent samples from 1972 - 73 produced growth indices close to the Ontario average (96.9% and 104.0%). A 1979 data set showed slightly faster growth (108.0%), but the samples were not strictly comparable and the significance of the difference could not be ascertained.

The growth rate of northern pike appeared to increase between 1975 (84.7%) and 1979 (94.8%) (assuming consistent age assessment) but even with this change the rate remained well below the Ontario average.

The reported diet for northern pike in Eagle Lake is extremely diverse, suggesting strong competition for food. Eleven species of fish, including small northern pike, were observed in stomachs in the single year of sampling. Invertebrates were commonly encountered, with both crayfish and mayflies outnumbering most fish species among recognizable food items. This type of diet for northern pike is often associated with slow growth.

Information on maturity is general and limited to walleye. Mature males occur first at age III and 50% maturity would appear to occur at age IV. Some females are mature at age V, but 50% maturity would seem not to occur until age VII. If we place the number of growing-degree days at 1650, based on the latitude of Eagle Lake, the maturation schedule for female walleye falls at least one year later than the norm depicted in Figure 12.

Data affording estimates of the mean age of catches are available for very few years. In 1979, mean ages of walleye and northern pike retained by anglers were 4.6 and 5.2 years, respectively. From size frequency and growth data, we would infer that the mean age of walleye caught and kept by anglers in 1973 was similar. Tag recovery data and differences in the composition of catches from the angling fishery and from experimental gillnets suggest that walleye become less vulnerable to angling with age in Eagle Lake. Consequently, the age structure of the catch is likely a

poor reflection of the population structure. The mean ages of male and female walleye taken during the spawning run at Whiteclay Narrows in 1972 was 6.6 and 9.4 years. Samples with which to examine lake whitefish mean ages are few and small. They indicate a mean age of approximately 7 years in the central part of the lake where the fishery is based. A sample from a little exploited population in the western arm of the lake had a mean age of 11 years.

Angling pressure is known for only 1973 and 1979 when data from creel censuses place it at 6.2 and 4.7 man-hr ha^{-1} yr^{-1}. This might be termed moderate pressure if it is assumed to be evenly distributed. From estimates of pressure by census sector (Charles 1979) it would seem that such an assumption is not seriously violated.

Eagle Lake - appraisal

We wish to preface our appraisal of Eagle Lake with two statements. First, the fisheries data examined date back from 1979. The interpretation of that data, therefore, should not be construed as applying to the current situation. Secondly, Eagle Lake is an extremely large lake with ample evidence of multiple stocks of some species. As the data preclude delineation and separate treatment of these stocks, the following appraisal applies to the "average" condition. We would recommend a more detailed look in the near future.

Our overall impression of Eagle Lake, as far as the species examined are concerned, is not one of overexploitation. While the estimate of potential yield has been exceeded by a slight margin, both yield and species composition have remained relatively stable over a long period of time. The elevated phosphorus component of TDS suggests that the morphoedaphic index may, in fact, be a very conservative estimator of potential yield in

the case of Eagle Lake. Viewed in the context of the lake's productivity, fishing pressure has not been high, and certainly fishing has not imparted high mortality rates. Abundance would appear within acceptable limits from a productivity standpoint, as would mean ages.

Age at first maturity for walleye is high enough to suggest that there has not been a major shift in the maturation schedule.

The growth data on the three species are too few to draw hard conclusions but they do offer some insights. Both lake whitefish and walleye appear to have been growing at a rate slightly above the Ontario average (106% and 103%, respectively). However, the significance of these differences is difficult to assess. Some size at age data for Shoal Lake walleye indicate that a heavily exploited population at this latitude might attain a growth index of 113%.

Northern pike, on the other hand, were growing at a rate that was below (approximately 90%) the Ontario average. Recent data (1982) from two equally northern populations indicate that growth rates well above the average are possible at these latitudes (e.g. Lake Nipigon -- 110%; Dogtooth Lake -- 114%).

All three species, especially pike, appear to have some scope for increased growth rate. Assuming that growth rate and exploitation are related, it appears that northern pike were least heavily exploited of the three species. Catch data support this view. Although the walleye and lake whitefish were growing at faster rates, these rates were not high enough to indicate more than moderate levels of exploitation.

Flack Lake - data synopsis

The yield, all in the form of lake trout, averaged 1.35 kg ha^{-1} yr^{-1} over the period 1968 - 1979. This was above the estimated potential yield (RYI = 1.07) and well above any guideline for a single species.

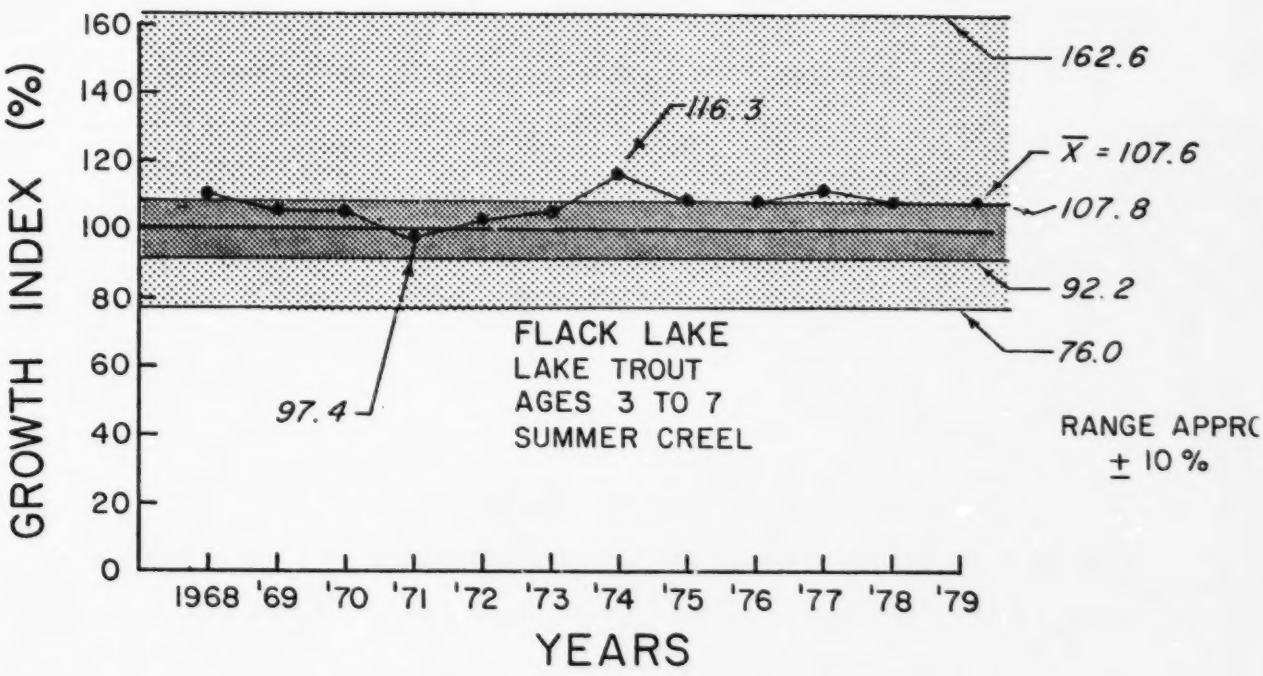
Fishing quality remained good, with an average CUE of 0.22 (range 0.16 - 0.31). The coefficient of variation in abundance for the study period was a low 0.20 (guideline, 0.35). Year-class variation remained within a narrow, threefold range.

Total mortality was estimated to be 0.80 over the age range 6 - 10 years, with fishing and natural factors contributing about equally to deaths. This mortality rate greatly exceeds our guideline (0.50).

Growth rate of lake trout from Flack Lake was difficult to evaluate in terms of the indices used here. All samples were collected from the summer creel and back-calculated size at age was not available. Hence, these data sets cannot be legitimately compared with the average growth indices, but can be used to provide a general impression of trends. This type of sample resulted in a growth index that exceeded the Ontario average (Figure 13). Although fishing pressure had been heavy, there was no overall trend in growth rate or growth compensation from 1968 to 1979, with the possible exception of a four-year period from 1971 to 1974. Over that time, the growth indices increased by approximately 20%. This deviation of approximately 10% about the mean is greater than would be expected due to normal sampling variability. This, of course, assumes that each year the samples were collected when the fish were in the same phase of the seasonal growth cycle.

More of these data sets (42%) could be fitted with the von Bertalanffy model than was possible with other provincial lake trout growth data (27%). The omega value, which provides a better indicator of growth for samples

Figure 13. Growth indices for lake trout from Flack Lake. The Ontario average is provided (smallest and largest data sets are delineated by lightly shaded area and 95% confidence limits by the darkly shaded area) for the age range used in the comparison.



collected from within the growing season than does size at age, was 57% above the Ontario average for the species.

Male lake trout in Flack Lake begin to mature at age 4, females at age 5. Both sexes attain more than 50% maturity one year later. This is in the lower range of ages for maturity in the species. Mean age of sexual maturity was 5.9 years (assumed to be for females) for the period 1968 - 1974.

Mean age of the annual catch averaged 5.4 years over a twelve year period, but the average went from 5.6 over the first six years to 5.2 over the later six. The Abrosov index determined from the twelve year average is -0.5 years.

Fishing pressure has remained fairly stable, averaging 7.1 man-hr ha^{-1} yr^{-1}.

Flack Lake - appraisal

On the strength of the foregoing observations, we consider Flack Lake to be essentially at the limit of sustainable yield, with little room left for compensation. The high yield, high mortality rate in the adult component of the trout population, above average growth and early maturity point to heavy exploitation. On the other hand, the fishery has remained amazingly stable in terms of yield, catch rates and recruitment. The simplicity of the fish fauna may indirectly account for this stability. Nutrients and energy seemingly are not being diverted to other species but are remaining with lake trout, enabling compensating mechanisms to operate to the fullest degree.

Although lake trout first enter the fishery in small numbers at age 3, the modal ages in the various years have been 5 and 6. With the harvest centered on ages close to the mean age at maturity, it appears that the spawning stock thus far has remained above the critical level.

Summary

Neither appraisal above placed the level of exploitation on any scale. To create such a summary, values on an arbitrary scale of 1 - 10 were assigned to indicators according to the interpreted level of stress, with ranges 1 - 3, 4 - 6, and 7 - 10 corresponding to low, intermediate and high stress, respectively. Overexploitation might be considered to occur at level 7 or higher. The assignments, which were made independently by several group members, are tabulated in Table 9.

Agreement on interpretation was good at both the individual index level and at the overall level of appraisal. There is danger in making a final decision strictly on the basis of score. Therefore, it is recommended that such ranking only be done to give individual analysts a means of comparing interpretations.

Table 9. Numeric representation of stress level. Values on a scale of 1 - 10 were assigned independently by working group members to reflect their interpretation of stress level for each indicator used in the appraisal of exploitation on Eagle Lake (3 reviewers) and Flack Lake (2 reviewers). These values were averaged to produce the table entries.

INDICATORS	LAKE AND SPECIES			
	EAGLE LAKE			FLACK
	L. Whitefish	N. Pike	Walleye	L. Trout
yield	5.7	4.3	4.7	7.5
CUE		4.7	4.7	5.5
pressure		4.3	5.0	7.5
growth	5.3	4.0	5.0	7.0
maturity			4.3	6.0
mortality	4.0	4.0	4.0	9.0
mean age	5.3	4.7	5.0	6.0
Abrosov index			6.0	7.0
average	5.1	4.3	4.8	6.9

DISCUSSION

A more empirical approach to the identification and quantification of indicators would have been preferred but attempts at gathering data sets for lakes that were clearly over- or underexploited met with little success. Few lakes for which good data exist in accessible form have been stated categorically to be overexploited. The very problem that we are trying to solve -- how to identify overexploitation -- has prevented workers in the past from either forming or stating an opinion concerning the status of fisheries.

Other stresses, notably cultural eutrophication and introductions of exotics, can produce changes similar to some of those associated with exploitation (Christie *et al* 1972, Colby *et al* 1972). Hence, changes in population or community characteristics reflect exploitation stress only if other forms of stress are, for all practical purposes, inoperative. It would be unsafe to assume that exploitation is the only stress throughout most of Ontario. Where more than one stress is recognized, the indicators will reflect combined effects to some degree and it will remain for the manager to decide which one(s) is having a significant impact. The indicators will offer clues. In this respect, one or more indicators that relate directly to exploitation, such as fishing pressure and yield, should always be included. Total mortality, if low, is a good indication that fishing is not excessive, but it might not reflect on past conditions if fishing pressure has declined.

Fisheries that are undergoing rehabilitation or that are supported in whole or in part with plantings of cultured fish may require some basis other than the listed indicators for evaluation. The indicators do not lose their biological relevance; it is the perception of overexploitation in light of management objectives other than stock

maintenance that can change. If restoration of a population in the shortest possible time is the objective, any amount of fishing may constitute overfishing. At the other end of the scale, in a purely put-and-take fishery with no community stabilization objective, biological overexploitation ceases to be a reality.

Reliability is a concern with any set of indicators. A test of the reliability of the indicators using data sets representing "known" instances of over- and underexploitation was conceptualized. Indicators were to be ranked according to the fraction of the time that each accurately categorized the state of a fishery. This fraction, raised to some power, was considered a possible arithmetic index of reliability. This approach would require data sets for previously classified lakes, independent of those used for indicator development, and these were in too short supply. Hence, testing will have to occur through use.

There is danger in defining a single set of guidelines for over-exploitation as we in some cases have done. Our concern is with the ability of fishery resources to support yields. Entire fish communities may be conservative in this respect but populations within individual species can exhibit considerable differences in productivity and resilience, depending on how well habitat requirements are met. Ideally, there should be different guidelines for different sets of conditions as they are known to bear on attributes such a growth, recruitment, survival and behaviour. For the time being, we can only suggest that guidelines be used with discretion.

The time-series data that would be preferred in any analysis of the state of a fishery often will not be available. Of the various indicators, several lend themselves to point-in-time application. Point-in-time in this case may be one year, but could also be several years over which averages are taken. The indicators judged suitable for use over a short

term are yield, abundance, growth, and total mortality: yield because there is a tested estimator of a lake's potential; abundance because it is a general indicator of well-being; growth because it is responsive to biomass change and there is a provincial standard for comparison; and total mortality because it is a direct measure of the extinction rate of cohorts. Obviously, there are others of the set which could be applied, but these are the ones which we would choose.

It is clear from our search for pertinent data sets from within the province that greater standardization and better documentation will be necessary if across-lake comparisons are to be successful in future. This is particularly true of abundance data. We had difficulty putting CUE in a provincial perspective because CUE is typically expressed only in numbers per unit of effort. Abundance in numbers does not necessarily correlate well with the biomass of a species. For example, planktivorous and piscivorous populations of lake trout of equivalent biomass may differ vastly in their numeric size because of the typically small average size of the planktivores. Given equal catchability, the planktivorous population would produce much higher catch rates, even though yields might be similar. In future, CUE should be calculated in both number and weight to allow comparisons on either basis.

If the concept of "harmonic" communities (Ryder and Kerr 1978) is valid, the ability of a fish community to persist and maintain its integrity under exploitation would depend on how closely abiotic conditions of the environment approach the ideal for that community type (eg. a percid community). At this point in time, the quantification required to give the concept practical application in a diagnostic sense is lacking. However, we would suggest that it not be overlooked. It offers a rationale for community "typing" and may help to explain observed events at the community level. Certainly, it offers incentive to

seek out community parameters and to document variability in community structure, if only to explore the concept further.

Although growth is a useful indicator of exploitation and has been widely used, it must be considered more carefully than in the past. The significance of a change in growth rate must be evaluated in terms of scope available for change. Maximum growth rate is not necessarily desirable because it could occur when the population density is less than that which is optimal. A rate slightly less than, but approaching the maximum is probably more desirable. More growth data should be collected to refine the growth indices and subsequently to calibrate them in relation to different levels of exploitation. In addition to previous recommendations made concerning growth, a set of guidelines is provided for those considering growth data (Appendix 5).

In future, other indicators may be added. Early results indicate that fecundity in walleye is responsive to density changes produced by exploitation (P.J. Colby, pers. comm.). However, only recently have such changes become the object of study within the province and it will likely be some time before there is an adequate factual basis for the use of fecundity as an indicator. Because the potential is there, we advocate that this data element be incorporated in long-term data collections.

Another indicator that deserves future consideration is mean age of the spawning stock, relative to the age at onset of maturity, Similar in some respects to the Abrosov index, this indicator would serve as a measure of survival beyond maturity and of opportunities for multiple spawning. For relevance, it should be computed separately for the two sexes and, at the time of interpretation, attention should be given to the distribution of ages about the mean.

We have described a diagnostic approach to the identification of overexploitation which depends on recognition of common responses of

populations or communities to fishing. This recognition and insight into the scale of each response can be gained through documented case histories in both time and space. The spatial aspect is important as it permits rapid accumulation of new or additional information through structured assessment of lakes selected to represent a range of habitat and stress conditions and species assocations. With the diagnostic approach there is no fixed amount of data required to evaluate the condition of a particular fishery. In general, the more indicators that can be included, the better the test. But even a modicum of data will allow comparison with a subset of indicators.

Until now, nothing has been said about the various stock assessment models used to optimize yield and recruitment within a single stock. These models rely on longterm data series specific to each stock being managed. Only in some of the larger lakes in Ontario where economic benefits directly ensuing from a stock are high will the expense of such intensive management be justified. By far the majority of provincial lakes will be managed extensively. It is for these lakes that we advance a set of indicators although it is our hope that workers will find indicators useful in all situations.

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APPENDIX 1

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APPENDIX 2

r and K selection

	r selection	K selection
selection favors	rapid development	slower development
	high maximum population increase	greater competitive ability
	early reproduction	delayed reproduction
	small body size	larger body size
	single reproduction	repeated reproduction

Appendix 3-1. Data sets (18) used to examine size at age and growth of northern pike populations from 12 bodies of water in Ontario.

# of data set	Body of water of origin	TL converted to FL[a]	Assessed scale age												Additional ages	Authority
			1	2	3	4	5	6	7	8	9	10	11	12		
1	Wickett Lake 1970	×	24.1	38.0	43.6	48.4	51.5									Casselman 1974
2	Smoky Hollow Lake 1968		20.3	36.0	47.1	52.8	56.0	58.6	59.4							Casselman 1974
3	Smoky Hollow Lake 1970	×	31.2[I]	46.5	49.4	58.1										Casselman unpublished
4	Willow Creek-Minesing Swamp 1974			28.4[S]	38.9	52.1	53.1									Casselman unpublished
5	Niagara River 1975-76	×	23.4	36.4	46.3	55.0	62.8	67.4	71.2							Harrison 1978
6	Upper St. Lawrence River 1964	×	16.7	33.6	44.4	52.6	59.0	62.9	68.2							Casselman 1964
7	Upper St. Lawrence River 1967	×	22.5	36.7	48.2	55.2	60.2	63.8	67.2							Casselman 1967
8	Upper St. Lawrence River 1978			39.0	51.6	58.5	65.7	73.9[I]	76.6[I]							Dunning et al. 1978
9	St. Lawrence River 1956	×	20.8	34.9	43.8	49.1	56.9	59.3	63.8							McLeod 1961
10	Lake St. Lawrence 1961	×	26.0	46.5	58.9											McLeod 1961
11	Lake Simcoe	×	15.2[S]	30.4	41.7	53.0	61.0	69.4	76.1	81.4[I]	85.7[I]	91.3[I]	93.4[I]	96.8[I]	×	MacCrimmon and Skobe 1970
12	Lake Ontario 1978	×	22.6	47.5[I]	61.4[I]	67.6[I]	71.0[I]	73.2	74.2	76.0						Wolfert and Miller 1978
13	Lake Ontario 1940	×	26.7	39.8	47.4	53.4	61.2									Greeley 1940
14	Ontario	×	21.8	33.7	41.2	49.6	55.2	61.9	68.6	75.7	81.4	84.3	85.7[S]	91.5[S]		Devitt 1958
15	Savanne Lake	×	22.6	32.8	39.6	46.0	51.8	58.3	65.2	73.7	80.2	84.6	87.3			Mosindy 1980
16	Lake Erie	×	27.1	41.9	50.7	56.4	61.0	63.2	68.5	72.1	74.6[S]	78.5[S]				Clark and Steinback 1959
17	Partridge River 1975	×		30.1	36.6[S]	40.7[S]	45.8[S]	47.9[S]	51.5[S]							Casselman unpublished
18	Shoal Lake	×	25.1	35.3	41.8	46.9	48.6	52.5	56.0	59.9[S]						Ruth et al. 1980
N			15	18	18	17	16	13	13	6	4	4	3	2		
Grand mean			23.07	37.08	46.26	52.67	57.55	62.49	66.65	73.13	80.48	84.68	88.80	94.15		
SE			1.040	1.330	1.542	1.453	1.629	2.080	2.090	2.942	2.287	2.617	2.346			

[a] $Y_{FL} = -3.931 + 0.947X_{TL}$ (Casselman unpublished data)
[S] Smallest FL
[I] Largest FL

Appendix 3-2. Data sets (38) used to examine size at age and growth of walleye populations from 23 bodies of water in Ontario.

# of data set	Body of water of origin	TL converted to FL[1]	Assessed scale age																	Additional ages	Authority
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	Big Trout Lake	*	14.1	18.7	24.0	31.3	34.0	49.0	42.9	46.0	47.9	56.8	50.7	55.6	57.1	55.4		63.3	55.6[a]	63.5[f]	*	Armstrong 1961[1]
2	Deer Lake	*	10.3	11.0[a]	18.5	26.6	29.4	34.0	36.4	42.0	43.6	47.2	48.9	54.0								Armstrong 1961[1]
3	North Caribou Lake	*	10.3	16.0	20.4	24.4	29.0	29.7[a]	35.0[a]	38.6	40.7	43.1[a]	43.6[a]	46.5[a]	49.1[a]	54.1		54.9[a]	59.6	57.2[a]	*	Armstrong 1961[1]
4	Nakoop Lake	*	7.2[a]	16.0	21.2	25.2	28.8	33.6	37.2	39.0	42.0											Armstrong 1965[1]
5	Lake St. Joseph	*	9.1	15.6	21.8	26.8	31.9	35.9	39.5	42.4	44.5	49.6	51.8	56.5								Lewis et al. 1964[1]
6	Sabaskong Lake	*	7.9	16.5	21.3	25.2	29.0	32.1	35.0[a]	37.6[a]	40.7	43.1[a]	45.6									Lewis et al. 1964[1]
7	Wunnumin Lake	*	9.1	15.4	20.6	25.2	29.7	33.3	36.4	39.5	39.5[a]	45.3	47.4	50.7	54.9	60.6	63.9[a]					Lewis et al. 1964[1]
8	Lac Des Mille Lacs	*		21.9	24.0	32.3	35.7	38.0	43.6	48.9	52.4											Elsey and Thompson 1977[1]
9	Lake Attawapiskat (1)	*	7.2[a]	13.2	18.0[a]	22.7[a]	27.4[a]	31.6	35.0[a]	37.8	40.0	43.6	44.5									Lewis et al. 1964[1]
10	Lake Attawapiskat (2)	*	7.6	13.7	18.7	23.5	27.8	32.1	35.2	38.6	43.1	44.8	47.2	51.5	55.6	54.0[a]						Lewis et al. 1964[1]
11	Petawitiip Lake	*	7.9	17.0	23.7	29.4	33.8	37.6	40.3	42.5	44.5	45.6	48.9									Lewis et al. 1964[1]
12	Sandy Lake	*	8.6	17.4	24.4	29.7	34.0	37.8	40.5	43.9	46.0	48.4										Lewis et al. 1964[1]
13	Lake of the Woods	*	13.3	19.1	23.9	27.8	30.7	34.5	37.7	41.2	44.7	47.0	49.4	50.2	53.4	54.7						Carlander 1945[1]
14	Savanne Lake	*	11.2	18.7	25.2	30.9	36.4	41.2	45.7	49.3	52.7	57.7										Colby unpublished[1]
15	Lake Huron	*		26.1	34.5	40.3	44.3	49.6	53.2	56.5	59.1	61.1	58.5									Payne 1965[1]
16	Three Mile Lake	*	11.5	17.3	22.3	27.5	29.7	34.5	36.9	47.2	58.7											Slastenenko 1956[1]
17	Lake Erie 1965	*	19.0	26.8	39.0	48.4	53.4	59.6[f]														Scholl 1965[1]
18	Lake Erie 1966	*	19.4	33.1[f]	39.3																	Scholl 1966[1]
19	Lake Erie 1967	*	19.4	31.1	41.2[f]	53.4[f]																Seward 1967[1]
20	Lake Erie 1968	*	19.0	32.1	40.7	49.8																Seward 1968[1]
21	Lake Erie 1969	*	17.7	31.4	40.0	47.2	54.6[f]															Baker 1969[1]
22	Moon River 1968-72	*		30.1	37.8	43.3	49.2	53.2	56.2	59.1	61.5	63.9	66.2	67.9	69.6[f]	71.2[f]	71.7[f]	72.9[f]	73.2[f]			Winterton 1975[2]
23	Shawenanegge Basin 1962-76	*				42.9	49.1	53.4	57.3	60.2	63.8	64.7										Zimmerman 1967[1]
24	Lake St. Clair 1980		21.0	29.0	37.6	40.2	45.1	47.7	50.4	52.3	57.1	60.5	65.0									Unpublished summary[1]
25	Lake St. Clair 1979			28.7	36.6	42.2	45.0	47.2	48.9	51.9	54.6	60.9	66.7									Unpublished summary[1]
26	Lake St. Clair 1978			28.5	40.0	41.3	42.6	48.5														Unpublished summary[1]
27	Lake St. Clair 1977		22.2	33.0	36.6	38.9	45.1	49.8	52.0	50.7	60.7	66.1	65.2	72.6[f]								Unpublished summary[1]
28	Lake St. Clair 1976			29.4	35.1	43.5	44.6	48.7	50.6	55.0	58.1	58.9	60.9	60.1								Unpublished summary[1]
29	Lake St. Clair 1975			28.2	36.2	42.7	47.7	50.1	54.0	57.9	60.5	63.0										Unpublished summary[1]
30	Lake St. Clair 1974			28.6	37.7	38.8	42.7	46.8	51.0	54.6	56.4	60.3	63.7	51.6								Unpublished summary[1]
31	Lake St. Clair 1973			26.9	34.7	39.8	44.3	49.7	51.4	52.7	57.4	58.9	67.0[f]									Unpublished summary[1]
32	Lake St. Clair 1972			28.1	34.1	39.7	43.8	47.5	50.5	54.6	60.0											Unpublished summary[1]
33	Lake St. Clair 1971			28.4	35.7	41.8	45.0	48.3	52.3	55.8	56.6	61.0										Unpublished summary[1]
34	Lake St. Clair 1970		22.5[c]	30.2	38.2	41.7	46.1	49.4	55.3	58.8	57.1	59.6										Unpublished summary[1]
35	Mississagi River 1965	*				40.3	44.3	49.6	53.2	56.5	59.1	61.1										Payne 1966[2]
36	Nottawasaga River 1977	*				42.6	51.9	57.1	61.3[f]	64.1[f]	66.8[f]	68.6[f]										LeFrance unpublished
37	Lake Nipissing 1974-76	*				34.9	37.3	39.6	42.3	44.0	48.2	46.6										Jorgensen unpublished
38	Bulles Rapids 1973-77	*				35.4	41.3	46.3	51.7	55.7	61.3	63.7										Gunn 1979
N			22	33	33	37	35	34	32	32	32	28	18	11	6	6	2	3	3	2		
Grand mean			13.43	23.55	30.29	36.15	39.56	43.15	45.87	49.50	52.48	55.40	55.08	56.06	56.62	58.33	67.8	63.70	62.80	60.4		
SE			1.168	1.207	1.422	1.380	1.391	1.415	1.419	1.418	1.452	1.564	2.076	2.356	2.826	2.764		5.200	5.327			

[a] Converted using FL = 0.9432TL average from Colby et al 1979
[b] smallest fl
[c] largest fl

[1] Colby et al. 1979
[2] Gunn 1979
[f] Petzold MS 1981

Appendix 3-3. Data sets (15) used to examine size at age and growth of lake whitefish populations from 11 bodies of water in Ontario.

# of data set	Body of water of origin	TL converted to FL[a]	Assessed scale age																	Authority
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	Lake Lavieille 1966-75		6.9[e]	12.2[e]	16.3[e]	20.0	23.2[e]	25.9	28.0	29.6	30.7[e]	31.8[e]									Ihssen et al. 1981
2	Lake Opeongo 1966-75		11.9	18.4	22.5	25.4	27.7	29.5	30.6	31.2	32.3	33.2	34.4[e]	36.1[e]	38.2						Ihssen et al. 1981
3	Lake Opeongo 1953-61		10.8	16.2	20.8	24.7	28.8	32.9	26.5[e]	29.6	42.6	46.5	48.3								Sandercock MS 1964[1]
4	Lake Opeongo 1929-35		11.0	14.8	17.7	21.0	23.6	24.5[e]	26.9	29.6	35.3	40.4									Kennedy 1943[1]
5	Lake Simcoe 1958-70		9.7	16.6	22.2	27.2	31.3	34.1	36.6	38.6	40.2	41.8	43.1	44.3	44.7	45.5	46.9				Ihssen et al. 1981
6	Lake Simcoe 1950-62		9.8	16.5	22.0	25.3	32.6	34.0	34.9	36.3	38.4	39.1	40.6	42.7	45.7	48.1	51.9				Semple MS 1968[1]
7	South Bay 1967-75		10.3	17.3	23.3	27.7	30.8	33.4	34.9	36.6	38.0	39.8	42.1	44.3	52.8	53.6					Ihssen et al. 1981
8	South Bay 1931-39		9.6	15.5	20.4	25.0	28.5	31.4	34.2	36.4	38.0	39.7	41.2	42.3	44.0	45.8					Reckahn unpublished[1]
9	Lake Ontario		15.9	30.9	41.7	47.3[I]	50.4[I]	52.6[I]	54.3	55.7	56.7	57.0	58.1	58.6	59.2						Ihssen et al. 1981
10	Lake Erie		27.9[I]	34.9[I]	41.8[I]	44.6	47.8	50.6	53.0	56.8	56.8	56.8	57.8	60.2	61.0[I]	61.4					Van Oosten and Hile 1947[2]
11	Lake Ontario			22.7	29.0	37.3	45.1	46.2	50.8	49.9	54.1		63.3[I]								Hart 1931[2]
12	Georgian Bay				38.6	43.4	46.0	52.1	55.6[I]	58.0[I]	59.6[I]	60.9[I]	60.9	61.5[I]	60.6	62.3[I]	62.6[I]	62.3[I]			Cucin and Regier 1965[2]
13	Lake Nipigon			12.3	16.8	19.4[e]	25.4	26.9	28.1	31.6	36.1	40.2	43.1	44.1	44.9	45.4	48.8	49.5	50.4[I]	48.6[I]	Hart 1931[2]
14	Lake on Shakespeare Island		15.1	19.5	22.4	25.9	27.0	29.1	32.1	33.9	35.5	39.1	40.9	41.5	41.7	44.5	45.6	45.4	46.7[e]	46.5[e]	Hart 1932[2]
15	Lake Superior		13.4	17.5	20.3	22.8	24.5	26.2	27.9	29.3[e]	31.3	32.9	34.9	37.3	38.1[e]	38.8[e]	39.5[e]	40.5[I]			Edsall 1960[2]
N			12	14	15	15	15	15	15	15	15	14	13	11	11	9	6	4	2	2	
Grand Mean			12.69	18.95	25.05	29.13	32.98	35.29	36.96	38.87	41.71	42.80	46.82	46.63	48.26	49.49	49.22	49.42	48.6	47.6	
SE			1.560	1.746	2.238	2.396	2.505	2.575	2.785	2.757	2.579	2.469	2.740	2.737	2.613	2.662	3.159	4.669			

[a] $TFL = -2.310 + 0.96\ X_{TL}$ (Semple 1966)
[e] smallest FL
[I] largest FL
[1] Ihssen et al. 1981
[2] Healey 1975

Appendix 3-4. Data sets (42) used to examine size at age and growth of lake trout populations from 26 bodies of water in Ontario.

# of data set	Body of water of origin	TL converted to FL[a]	Assessed scale age															Authority
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Lake Opeongo			22.4	26.7	30.5	34.8	39.1	45.0	48.5	53.1	56.4	60.9	64.8	68.6	69.8[d]	71.6[d]	74.9[d]	Martin 1970
2	Lake Louise		10.4[d]	17.5	19.6	24.4	32.5	34.3	36.6	40.1	43.9[d]	52.1	50.8[d]	55.4[d]					Martin 1952
3	Bedrock Lake			14.7	18.8	27.7	33.6	40.1	45.2	49.3	53.8	63.5	72.9	74.9					Martin 1952
4	Proulx Lake									53.3	56.6	57.9	58.4	66.0	67.3				Martin 1952
5	Brewer Lake			14.0	24.1	27.2	29.5	32.0	35.6	35.6[d]									Martin 1952
6	Chicadee Lake						27.9	35.6	38.1	38.9									Martin 1952
7	South Bay			25.4[1]	32.2	41.9	47.8	52.3	57.7	78.7[1]	73.7								Fry 1953
8	South Bay				37.2[1]	48.4	53.1	55.2											Budd and Fry 1960
9	Lake Superior			11.4[d]	16.1[d]	20.3[d]	26.4[d]	32.0	37.0	41.7	46.4	51.8	54.4						Rahrer 1965[3]
10	Lake Superior		11.1[1]	16.8	21.7	27.8	34.4	43.1	47.8	53.4	63.7	71.0	76.2	81.4					Rahrer 1967[3]
11	Montreal River							58.4	62.9[1]	72.4	75.6[1]	77.5[1]	78.2	79.1		72.7			Loftus 1957
12	Dog River							47.0	54.0	61.0	62.2	66.7	68.6	71.1	76.2	78.2			Loftus 1957
13	Lake Manitou					51.3[1]	56.9[1]	59.7[1]	60.7				69.8	71.1					Budd et al. 1968
14	Georgian Bay--Lake Huron			22.0	29.0	33.0	42.0	49.0	54.0	58.0	64.0	64.0	65.0						Tomkins 1951[2]
15	Big Trout Lake	"		21.1	26.5	34.7	44.8	48.4	48.4	53.0	53.0	56.6	61.2	65.7	83.1	86.7[1]	87.6[1]	90.3[1]	Armstrong unpublished[2]
16	Lake Simcoe	"					50.2	56.6	60.3	64.8	69.4	71.2	72.1	73.0	73.0	73.0	73.0		MacCrimmon and Skobe 1970[2]
17	Big Sal Lake				22.3	29.6	33.7	41.9	52.8	56.0									Unpublished summary[3]
18	Gull Lake 1978	"			24.4	27.4	29.6	33.9	39.0	42.6	51.8	55.7							Unpublished summary[3]
19	Gull Lake 1979	"				27.4	31.0	35.5	39.8	47.4	50.8								Unpublished summary[3]
20	Muskoka Lake 1979	"					30.5	36.3	46.1	53.3	51.5								Unpublished summary[3]
21	Twelve Mile Lake 1978	"				25.1	30.8	38.4[d]	44.5	48.0									Unpublished summary[3]
22	Beshkung Lake 1978	"			23.6	23.2	27.4	34.7	40.0	45.8	51.1	56.5	60.6	61.1	68.9				Unpublished summary[3]
23	Lake Joseph 1978	"					26.4[d]	35.0	41.5	45.9	50.6	57.5	60.1	62.9	65.4[d]	75.2			Unpublished summary[3]
24	Redstone Lake 1978	"					29.5	33.2	38.9	43.6	47.6	53.4							Unpublished summary[3]
25	Kennisis Lake 1978	"				25.4	29.6	34.8	39.7	43.3	50.7	50.1[d]	54.3	63.8					Unpublished summary[3]
26	Lake Kawagama 1978	"				26.9	28.4	34.3	40.5	43.9	47.8								Unpublished summary[3]
27	Lake Kawagama 1979	"				27.2	31.9	37.0	42.1	44.2	49.4	59.8							Unpublished summary[3]
28	Nelson Lake 1980	"			22.2	26.2	35.3	36.1	43.0	50.6	62.2	60.4							Unpublished summary[3]
29	Lake Temagami 1978	"			27.2		34.2	42.4	54.1	60.2	61.5	74.9	85.0[1]	88.5[1]	94.0[1]				Unpublished summary[3]
30	Bone Lake 1968	"		16.0	18.1	22.9	29.9	32.5	37.7										Unpublished summary[3]
31	Bone Lake 1968	"			19.2	22.3	29.9	32.9											Unpublished summary[3]
32	Bone Lake 1969	"			18.8	24.5	30.5	35.2	46.3										Unpublished summary[3]
33	Bone Lake 1970	"			19.2	25.0	31.3	39.4											Unpublished summary[3]
34	Bone Lake 1971	"			17.9	22.7	28.0	32.9	35.5[d]										Unpublished summary[3]
35	Bone Lake 1972	"			19.2	25.0	30.5	37.0											Unpublished summary[3]
36	Bone Lake 1973	"			18.8	22.7	29.2	32.5	42.1										Unpublished summary[3]
37	Bone Lake 1974	"			22.4	28.2	33.8		53.3										Unpublished summary[3]
38	Bone Lake 1975	"			19.2	25.3	32.0	37.7											Unpublished summary[3]
39	Bone Lake 1976	"			19.2	23.2	30.2	37.7											Unpublished summary[3]
40	Bone Lake 1977	"			16.7	23.3	32.0	37.0											Unpublished summary[3]
41	Bone Lake 1978	"			23.2	23.9	32.0												Unpublished summary[3]
42	Bone Lake 1979	"			19.9	24.5	32.2												Unpublished summary[3]
N			2	10	28	33	39	38	32	27	23	19	16	14	8	6	3	2	
Grand mean			10.75	18.13	22.26	27.85	32.86	39.56	45.86	51.17	56.10	60.90	66.78	70.34	74.56	76.93	77.40	82.60	
SE				1.397	0.921	1.221	1.400	1.303	1.404	1.963	1.831	1.850	2.696	2.572	3.433	2.377	5.116		

[a]Converted using $Y_{FL} = 0.980 + 0.9116X_{TL}$ (Casselman unpublished data)
[b]Smallest fl
[c]Largest fl
[1]Healey 1978
[2]Martin and Olver 1980
[3]Petzold MS 1981

TABLE 2. *Relationship between rate of maturity of female walleyes and growing degree-days above 5°C (GDD > 5°C). Given also are the relative fishing pressure (RFP) on the walleye stock as surmised from personal communication and the literature: L = lightly fished, M = moderately fished, H = heavily fished, N = negligible fishing, and ? = unknown. Type of fishery: C = commercial fishery, A = angling, and E = experimental fishing using various gear. Time of year the stocks were sampled for estimating maturity: Sp = spring, Su = summer, F = fall, W = winter, and U = unknown. Percentages in parentheses not calculated by original authors, but from the data given in their papers (for Pike Lake only assumed 1:1 sex ratio among two immature fish used in calculations); those percentages in brackets are females which were developing at time of sampling (TOS) but had not yet attained maturity.*

Location	Age at maturity (females)[a]									GDD > 5°C	RFP	TOS
	2	3	4	5	6	7	8	9	10			
Mosquito Cr., NWT[b]							×[b]	(65.4)	(100.0)	967	L-M:A	Sp-Su
Southern Indian L., Man.[c]				×[c]				××	××	1013	M:C	Sp
Hay R., NWT[d]							×[d]		×	1022	M:A	Su
Big Trout L., Ont.[e]					50.0	100.0				1043	?:C	U
N. Caribou L., Ont.[f]						71.0	80.0	88.0	100.0	1156	?:C	U
Lac La Ronge, Sask.[g]				×[e]		50.0	××	××	××	1178	?:C,A	Sp
Deer L., Ont.[h]					33.0	43.0	93.0	100.0		1281	?:C	U
Savanne L., Ont.[i]				43.0	75.0	86.0	78.0	100.0		1287	N:E	F
Dexter L., Ont.[j]			(25.0)	(37.5)						1287	L:A,E	Su
L. Winnipeg N., Man.[m]			5.3	10.4	28.1	50.0	58.3	100.0		1422	M:C	Su,F
L. Winnipeg S. Man.		2.3	8.3	3.0	14.3	0.0	0.0	0.0		1631	H:C,A	Su,F
		[0.0]	[2.4]	[9.1]	[25.0]	[60.0]	[50.0]	[100.0]				
L. of the Woods, Ont., MN[n]			4.0	33.8	31.2					1657	H:C,A	W,F
Escanaba L., WI[o]			43.0	83.3	75.8	85.2	100.0			1901	H:A	F
Georgian Bay, Ont.[p]			×	××						1906	H:C,A	Sp
L. Winnebago, WI[q]			8.0	32.0	67.0	81.0	100.0			2187	M:A	F,W
Pike Lake, WI[r]		×	(99.0)	(100.0)						2273	H:A	Sp
Western L. Erie[s]	1.0	100.0	98.6							2600	H:C,A	W,F,Sp
L. Meredith, TX[t]	(36.0)	86.3–××								3691	L:A	Sp
Center Hill Res., TN[u]	(26.3)	(80.0)	(100.0)							4078	L:A	Sp
Canton Res., OK[v]	6,2	88.9								4145	L:A	Sp
El Capitan Res., CA[w]		××								4436	L:A	W,Sp
Canyon TX[x]	×	××								5680	L:A	W,Sp

[a]Percentages of mature fish from the total number of fish sexed in a certain age-group; where we were unable to calculate percentages, × refers to age at first maturity and ×× refers to age(s) where most mature or modal age(s) where most fish appear to be reaching maturity.

[b]The few (6) females were 100% mature, but not considered representative of the actual percentage reaching maturity of that age-group since so few were captured.

[c]Youngest mature females were age 5, but modal ages were ages 9 and 10.

[d]Females do not spawn before age 8, youngest spent female observed by Bond et al. (1978) was age 10.

[e]A few age 5 females enter spawning run, but bulk of the run was ages 8–10.

[f]Falk et al. (1980), Gillman (personal communication. [g]Bodaly (1980). [h]Bond et al. (1978). [i]Armstrong (1961). [j]Rawson (1957). [m]Romani (unpublished data) [n]Moening (1975). [o]Lysack (1980). [p]Carlander (1945). [q]Serns (unpublished data). [r]Winterton (1975). [s]Priegel (1969) [t]Mraz (1968). [u]Parsons (1972). Wolfert (1969) [v]Kraai and Prentice (1974). [w]Muench (1966) [x]Grimstead (1971). [y]Miller (1967). [z]Prentice (1977, personal communication).

APPENDIX 5

Growth Indices - Guidelines for data collection

1. When comparing within and between populations, data sets of size at age must contain fish that are precisely the same age, especially in relation to seasonal growth. Empirical data should come from fish that are in the major growth cessation that occurs annually. For most species, this would be the period from autumn to spring. If back-calculated data are used, the structures used to prepare the structure-body relationship and in the back-calculation should be collected when the structure (or fish) is in the growth cessation that results in the deposition of a check or zone that is associated with the annulus. This would be just prior to annulus formation. Hence for most warmwater and coolwater species, the data should come from the period during late autumn to early spring.

2. Age assessment should be validated, or at least verified, and the assessment must be reliable and consistent (see Casselman 1982).

3. The scale method should be treated with caution for fish that are suspected to be old or slow growing.

4. Data should be separated by sex or, if combined, at least equally weighted.

5. When comparing several data sets, the sampling procedures should be similar (e.g. time of year, gear, etc.).